CRUNCHING NUMBERS

QUANTIFYING THE SUSTAINABLE DEVELOPMENT CO-BENEFITS OF MEXICO'S CLIMATE COMMITMENTS

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WELCOME MESSAGE

Climate change is the biggest challenge of our time. It is impacting all ecosystems and the lives of all people. However, we are at a decisive moment to act on behalf of our country and the planet.

In light of this challenge, the Office of the Presidency, through the 2030 Agenda Directorate, is convinced that in order to achieve economic development and the well-being of all people, it is necessary to adopt an approach of sustainable development that addresses the structural causes of vulnerability, environmental degradation, the exploitation of natural resources, inequality and poverty. Such a transformative approach will encourage the incorporation of all multisectoral efforts to ensure an emissions neutral and resilient future, where no one is left behind. It is a historic moment to face the challenge as an opportunity to embrace innovation, forge partnerships in the unlikeliest of places, and treat disruption as a strength, not as a disadvantage. It is time to react, to make a difference for the climate and for a better and sustainable world for all. It only depends on us.

I therefore thank German Development Cooperation for the collaborative and close work to advance towards the mainstreaming of climate action in public policies. I also thank the various agencies of the federal government that contributed in all stages of this project providing information, models, data and technical support, which has allowed to strengthen the analysis of the climate action co-benefits for sustainable development in Mexico.

We celebrate this quantification study, urging the public, private, social and academic sectors to promote actions that increase knowledge generation, commitment and collective national ambition to achieve sustainable development, as well as climate change mitigation and adaptation actions, in order to build more inclusive societies.

MÉXICO
PRESIDENCIA DE LA REPÚBLICA

Ing. Alfonso Romo Garza
Chief of Staff
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FOREWORD

Fighting climate change and promoting sustainable development are the most imperative responsibilities of the international community. Mexico has played an important role in the negotiation, ratification and defense of international commitments that have resulted in the global agendas that today guide efforts to guarantee a more prosperous future for all.

The 2030 Agenda for Sustainable Development was adopted as a road map for poverty eradication, protection of the planet, and the wellbeing of all people, without compromising the development of future generations. The framework focuses on achieving sustainability and is prospective and cross-cutting. Its principles highlight the relevance of the comprehensiveness, interconnectedness, indivisibility and universality of development processes. As climate change is concerned, following the Paris Agreement, Mexico formulated its Nationally Determined Contribution (NDC) with an ambitious set of mitigation and adaptation measures to reduce Greenhouse Gas (GHG) emissions and limit the increase in global temperature to 1.5-2°C.

Climate change can reduce, hinder and even reverse development progress. Due to its geographic characteristics, Mexico is a highly vulnerable country to the effects of this phenomenon, which has the potential to generate social, environmental, and economic damages, disproportionately affecting vulnerable populations. Therefore, only if we approach climate change as a precondition for development can we guarantee the wellbeing of our country, ensuring that no one is left behind.

We must think of climate action as an opportunity. As the present study demonstrates, climate action has the potential to substantially promote our country's development. For example, accomplishing the NDC goal to achieve 43% of electricity generation from clean sources by 2030 can be an important catalyst for social development through improvements in public health (SDG 3). This would account for USD 2.7 billion in savings between 2019-2030 of funds usually spend for the treatment of air pollution related diseases. This amount is equivalent to 41% of the budget allocated to the Ministry of Health (SALUD) for 2019- savings that are extremely useful in a context of austerity.

Understanding and measuring co-benefits contributes to identifying opportunities to accelerate progress in both the 2030 and climate change agendas: it guides decision making, avoids the duplication of efforts, and reduces the costs of implementation. Mexico has institutional capabilities that can contrib-

ute to accelerate action to achieve both the Paris Agreement and the 2030 Agenda in a comprehensive manner. To seize these opportunities, it is urgent to mainstream climate change mitigation and adaptation in development planning. Climate action and development policies can and must be harmonized and integrated because far from opposing each other, they reinforce one another and can therefore achieve more together.

In coordination with German Development Cooperation, this study is presented as an essential first step to break the pattern of working in silos, by quantifying a selection of important social, economic and environmental co-benefits of climate action in various sectors and their impact for the achievement of the 2030 Agenda. Climate action must then be understood as a lever that enables the achievement of the 17 Sustainable Development Goals (SDGs), since a truly inclusive and sustainable development cannot be accomplished if the economic, social and environmental dimensions are not strategically integrated.

For the Government of Mexico, the construction of a more sustainable society is a challenge that requires comprehensive solutions and a permanent commitment of the public, private, social and academic sectors. In this sense, this study contributes to the generation of national evidence that will allow us to advance towards an integrated implementation of both agendas, in order to continue working for human development, inclusion and resilience. Understanding that the relation between sustainable development and climate change goes well beyond SDG 13 (Climate Action) can lead us to a new paradigm in which climate action is considered a pivotal part of development policies, and in which development strategies are conceived as vital for climate change mitigation and adaptation. The pursuit of inclusive development is relevant for all Mexicans and the entire global community alike. Thus, we must all unite on the path of mitigating climate change to achieve a truly sustainable development.

Dr. Abel Hibert Sánchez
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ACKNOWLEDGEMENTS

ABBREVIATIONS

BAU	Business as usual scenario
BEVs	Battery electric vehicle
BOD_5	Five-day Biochemical Oxygen Demand
CBs	Co-benefits
CBA	Cost-benefit analysis
CDMX	Mexico City (Ciudad de México)
CFE	Federal Electricity Commission (Comisión Federal de Electricidad)
CFM	Community forest management
CMM	Centro Mario Molina
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CONABIO	National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad)
CONAFOR	National Forestry Commission (Comisión Nacional Forestal)
CONAGUA	National Water Commission (Comisión Nacional del Agua)
CONAVI	National Housing Commission (Comisión Nacional de Vivienda)
CONUEE	National Commission for Efficient Energy Use (Comisión Nacional para el Uso Eficiente de la Energía)
DRR	Disaster risk reduction
EFA	Employment factor approach
EJ	Exajoule
EnRes	GIZ Program Converting Solid Urban Waste into Energy (Aprovechamiento Energético de Residuos Urbanos)
EV	Electric vehicle
GHG	Greenhouse gas
Gt	Gigaton
GVC	Global value chain
GWh	Gigawatt hours
ha	Hectares
hm^3	Cubic hectometers
ICEVs	Internal combustion engine vehicles
IMTA	Mexican Institute for Water Technologies (Instituto Mexicano de Tecnología del Agua)
INECC	National Institute of Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático)
ISAN	Tax on New Automobiles (Impuesto Sobre Automóviles Nuevos)
ISR	Income Tax (Impuesto Sobre la Renta)
ISTUV	Tax on Vehicle Possession and Use (Impuesto Sobre Tenencia y Uso Vehicular)

LAFRE	Law for the use of Renewable Sources of Energy (Ley para el Aprovechamiento de las Fuentes Renovables de Energía)
LTE	Energy Transition Law (Ley de Transición Energética)
LULUCF	Land use, land-use change and forestry
$MtCO_2$-e	Metric tons of carbon dioxide equivalent
MWp	Mega-Watt peak
N_2	Nitrogen
NBS	Nature-based solutions
NCD	Non-communicable diseases
NDC	Nationally determined contribution
NOx	Nitrous oxides
NTFP	Non-timber forest products
OECD	Organisation for Economic Co-operation and Development
PECC	Climate Change Special Program (Programa Especial de Cambio Climático)
PEMEX	Mexican Petroleum (Petróleos Mexicanos)
PES	Payments for Ecosystem Services
PETE	Special Program for Energy Transition (Programa Especial de Transición Energética)
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PM	Particulate matter
$PM_{2.5}$	Particulate matter of diameter less than 2.5 micrometers
PM_{10}	Particulate matter of diameter less than 10 micrometers
PRODESEN	National Electric System Development Program (Programa de Desarrollo del Sistema Eléctrico Nacional)
PROSENER	Energy Sectoral Program (Programa Sectorial de Energía)
PV	Photovoltaic
RE	Renewable Energy
SD+	More ambitious scenario
SDG	Sustainable development goals
SEMARNAT	Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales)
SENER	Ministry of Energy (Secretaría de Energía)
SLCP	Short-lived climate pollutant
SME	Small and medium-sized enterprises
tCO_2	Tons of carbon dioxide
WWTP	Wastewater Treatment Plants

MAKING CLIMATE ACTION A SUCCESS FOR THE PEOPLE OF MEXICO

The government of Mexico has set a new tone in domestic political discussions by bringing forward an ambitious social and economic development agenda – putting development ambitions and people of all social and economic backgrounds in the centre of the debate. At the same time, Mexico's government has reaffirmed its continuing international commitment to combat global warming with determined national climate action.

Indeed, the 2015 Paris Agreement marked a milestone in the international response to combat climate change and ensure worldwide adaptation to its effects. As part of the accord, all Parties are required to present Nationally Determined Contributions (NDCs) outlining their efforts to mitigate greenhouse gas (GHG) emissions, with the objective to jointly limit the mean global temperature increase to 1.5 – 2°C relative to pre-industrial levels. The NDCs include a wide range of necessary measures, from economy-wide to sector-specific targets and policies and are meant to be revised and strengthened in the years ahead. Signatories report regularly on their mitigation and adaptation efforts, a key obligation to provide greater

transparency of national action and international progress (UNFCCC, 2018).

While Mexico's efforts are imperative for the future of the earth, a stable climate is also a key enabler to the country's development. The climate change scenarios described in Mexico's NDC predict increases in the mean annual temperature by up to 2°C in northern Mexico and between 1°C and 1.5°C for the rest of the country in the near-term (2015-2039) (Gobierno de la República de los Estados Unidos Mexicanos, 2016). Such change will have far-reaching negative implications across ecosystems, society and the economy.

Acknowledging Mexico's global responsibility as the world's 11th greatest emitter in 2017, the Mexican government presented an elaborate NDC in 2015 to reduce its emissions and address the impacts of climate change. Mexico is responsible for 1.4% of global GHG emissions (Gobierno de la República de los Estados Unidos Mexicanos, 2016), releasing 490 megatons of carbon dioxide ($MtCO_2$) (Global Carbon Atlas, 2019).

The NDC includes mitigation and adaptation measures spanning across several sectors, with an

overarching unconditional commitment to reduce GHG emissions by 22% and short-lived climate pollutants(SLCP) by 51% relative to its 2030 emissions projections. If a global agreement were to be reached regarding an international carbon price, carbon border adjustments, technical cooperation, access to low-cost financial resources and technology transfer, Mexico further commits to a conditional GHG emission and SLCP reduction of 40% (Office of the Presidency, SEMARNAT, & GIZ Mexico, 2018). Mexico will submit a new or updated version of its current NDC commitment in 2020 (UNFCCC, 2019).

While the main objectives of the NDC are emissions mitigation and climate change adaptation, their implementation can generate cross-sectoral development benefits (IASS, 2017b; Office of the Presidency et al., 2018). In fact, implementing NDCs induces considerable social, economic and environmental co-benefits, which renders climate action a fundamental imperative to achieve sustainable development as it is reflected in the 2030 Agenda for Sustainable Development. Considerable qualitative evidence suggests that decisive climate action brings about positive effects in a large number of the 2030 Agenda's 17 United Nations Sustainable Development Goals (SDGs) and its 169 targets, and thus serve as a driver for prosperous, equitable and just societies. Such climate co-benefits can be defined as "[…] direct or indirect benefits that result from an NDC action or project, in addition to reducing GHG emissions or increasing resilience to the impacts of climate change" (Office of the Presidency et al., 2018, p. 23).

However, the assessment and communication of social, economic and environmental co-benefits induced by climate action have only recently been highlighted in the international discourse. Similarly, while the mandate to "climate-proof" development efforts across sectors and thereby mainstreaming political, economic, and social activity towards central climate goals has gained prominence in recent years, policymakers are only beginning to understand the interrelations, mutu-

al impacts, feedbacks and trade-offs between climate and other public goals and activities. In a similar vein, while there is a growing body of literature identifying these links, country-specific co-benefits assessments and concrete numbers on their magnitude, i.e., quantifications, are still rare and only slowly becoming accessible to policymakers.

The limited country-specific evidence regarding the interrelations between climate action and development agendas can be assumed to be a main reason why in many countries climate and development policies are perceived to be conflicting rather than mutually enforcing (Helgenberger et al.,2019). Understanding the broader environmental, social and economic benefits (and trade-offs) of climate action allows policymakers to selectively design climate and development policies with knowledge and consideration of the full scope of benefits to be reaped for the people. In view of effective policy implementation, co-benefits assessments provide government ministries, departments and agencies with the connectors to coordinate political agendas across different sectors and levels, from national to regional to local. Quantifying and assessing the identified development opportunities of climate action is an important enabler to rally support and build coalitions of action among the public and private sectors and individual citizens. Ultimately, in view of global policy fora such as the UNFCCC Conference of Parties and the UN High-level Forum on Sustainable Development, smart climate policy design with consideration of co-benefits will "[…] contribute to the achievement of both NDC commitments and Sustainable Development Goals targets" (Office of the Presidency et al., 2018, p. 47) and send a strong and bold signal to international partners.

Responding to the above presented shortcomings of the current co-benefits discourse, the aim of this study is to provide country-specific intelligence on the interrelations between climate action and the achievement of the 2030 Agenda for Sustainable Development and the full scope of benefits.

The five selected existing and potential NDC (climate action) measures incorporate:

Achieving 43% of electricity generation from clean sources by 2030 (existing NDC)

Achieving a net-zero deforestation rate by 2030 (existing NDC)

Guaranteeing and monitoring the treatment of urban and industrial wastewater in human settlements larger than 500,000 inhabitants (existing NDC)

Achieving 500,000 Electric Vehicle (EV) sales in Mexico by 2030 (potential NDC)

Reducing energy demand in the three most energy intensive industrial sectors: Cement (by 1.8%), Chemical (by 9.6%) and Iron & Steel (by 14.7%) by 2030 (potential NDC)

The six selected co-benefits include:

Improving livelihoods and community resilience[1]

Improved public health

Contributing to food security

Improving the conditions of water resources

Employment creation

Contributing to energy security

The study goes beyond existing research by quantifying the co-benefits of current and prospective NDC measures and their contribution to development objectives and SDG targets. By exploring existing synergies, we illustrate how ambitious climate action can contribute to other Mexican development priorities. By verifying and quantifying the magnitude and significance of climate action for economic, social and environmental development objectives, this report strengthens the case for climate and development policy integration.

Note, however, that, due to limited resources, the scope of the study does not allow for an encompassing analysis of potential trade-offs or opportunity costs resulting from the associated NDC measures. This should be analyzed by means of subsequent research efforts.

This study analyses six priority co-benefits resulting from the implementation of three current and two potential Mexican NDC commitments (see Table 2). The study builds on a prior qualitative analysis (Office of the Presidency et al., 2018) on the inter-linkages and possible co-benefits between Mexico's NDC and the 2030 Agenda for Sustainable Development.

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[1] The co-benefit of improving livelihoods and community resilience was adapted from two co-benefits identified in Office of the Presidency et al. (2018) – reduced vulnerability and increased resilience – in order to have a more social orientation and extend beyond the primary objectives of adaptation measures.

GUIDANCE FOR THE READER: RATIONALE FOR THE SELECTION OF CLIMATE ACTIONS AND DEVELOPMENT BENEFITS

This report presents the results of a strategic co-benefit assessment in Mexico. Current policy directions and national conditions have been considered to increase the relevance of the results and connectivity to ongoing political deliberations. The subsequent chapter introduces the reader to the rationale and approach for selecting climate actions and co-benefits for quantification.

The report is further structured along key climate action fields for Mexico, including current and potential NDC measures – clean electricity generation, net-zero deforestation, wastewater treatment, EVs and clean transport as well as industrial energy efficiency. This structure along climate action chapters will allow readers the selective uptake of results and policy implications based on the respective area of interest.

Each of these five chapters introduces the reader to the current status of the respective climate action in Mexico with its mitigation and adaptation impacts, followed by an overview of the full range of co-benefits that the measure is tied to. After understanding the applied assessment methodology, the reader is presented with the results of the anal-

ysis. The results and their contribution toward the associated SDGs are then discussed. Each chapter concludes with suggested political implications and future research directions.

The report closes by inviting all stakeholders to connect the key findings across all climate action fields and sustainable development co-benefits, to activate the interrelations between national and international climate action and development agendas and by encouraging further research to reap the full scope of co-benefits for Mexico.

In order to ensure that the results relate to the current political discourse, the selected NDC measures and co-benefits to be analyzed are the result of an analysis of the development objectives of Mexico's current administration:

1. **Mexico's government agenda:** Priorities in the stated political agenda of the Mexican government are a key criterion and were assessed through the revision of major political documents as well as through consultations with the Office of the Presidency (OPR), and a range of government ministries. The prominence of co-benefits with NDC measures and SDGs was determined through

previous work, which identified the number of linkages of each co-benefit with the NDCs and SDGs. Co-benefits with a broader range of connections were assessed as being of higher value.

2. **Mexico's SDG priorities** were considered through consultations with the OPR and government ministries, as well as the review of government documents addressing the 2030 Agenda in Mexico.

3. **Mexico's NDC process**: Reflecting government priorities, both mitigation and adaptation-focused measures should be incorporated. For climate change mitigation action, the representation of key emissions sectors needs to be ensured. In view of the political deliberations on Mexico's 2020 NDC update, both current and potential prospective NDC actions were analyzed.

4. **Technical feasibility:** Lastly, two technical criteria – quantification potential and data availability – were applied to allow for a sound and valid assessment of co-benefits. This implied taking account of the degree to which the co-benefits had already been assessed in literature, whether established quantitative indicators existed for the co-benefits, as well as a qualitative assessment and initial scoping on availability of data for such co-benefits. Co-benefits with better established methodologies were favored over those for which new methodologies would need to be designed.

The study builds strongly on a prior qualitative analysis on the inter-linkages between Mexico's 49 NDC measures, the 17 SDGs of the 2030 Agenda and 25 possible co-benefits (Office of the Presidency et al., 2018). This study determined that there were extensive linkages between climate action and the 2030 Agenda, with almost 40% of the SDG targets being linked to mitigation and/or adaptation measures, and effectively all of the climate actions having additional social, economic and environmental benefits relevant to other sectors. The SDGs most connected to the co-benefits examined were SDG 12 (Sustainable Consumption and Production) and SDG 6 (Clean Water and Sanitation). The climate actions/targets with the most connections to co-benefits were 1) sustainable and resilient agricultural systems, 2) efficient use of water resources, 3) renewable energy and 4) sustainable transport systems. The study concluded that co-benefits are a starting point to strengthening policy coherence and that an integrated implementation approach is critical to maximizing the impact and reducing the costs of implementation and trade-offs.

For this strategic co-benefit assessment for Mexico, the subjects of analyses were systematically prioritized and selected based on defined criteria (see Table 1). This resulted in a set of five current and potential NDC (climate action) measures and six priority co-benefits (see Table 2).

Table 1: Prioritization and selection criteria set used for the analyses.

Climate action selection criteria	Co-benefits selection criteria
• Mitigation and adaptation-oriented measures	• Priority to the Mexican Government
• Key emissions sectors represented	• Prominence of co-benefits with NDC measures
• Current and prospective NDCs	• Prominence of co-benefits with SDGs
• Prominence of CBs with NDC	• Mexico's SDG priorities
• Quantification potential	• Quantification potential
• Data availability	• Data availability

Table 2: Co-benefits of climate actions linked and quantified in the study. Identified linkages are denoted by √'s and the selection of CBs to be quantified for the specific NDC measures is highlighted. Note that not all of the linkages could be quantified due to methodological reasons.

Climate Actions \ Co-benefits	Improving livelihoods & community resilience	Contributing to food security	Improving public health	Improving the condition of water resources	Employment creation	Contributing to energy security
Achieve 43% of electricity generation from clean sources by 2030	✓		✓	✓	✓	✓
Achieve a zero-deforestation rate by 2030	✓	✓	✓	✓	✓	
Guarantee and monitor the treatment of urban and industrial wastewater in human settlements larger than 500,000 inhabitants	✓	✓	✓	✓	✓	✓
Achieve 500,000 EV sales by 2030			✓	✓	✓	✓
Reduce energy demand in the three most energy intensive industrial sectors: Cement (by 1.8%), Chemical (by 9.6%), Iron and Steel (by 14.7%) by 2030	✓		✓	✓	✓	✓

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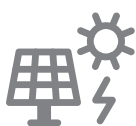
ENERGIZING MEXICO'S DEVELOPMENT WITH CLEAN SOURCES

KEY FINDINGS

- In addition to several other development benefits, meeting the NDC target of generating 43% of electricity from clean sources by 2030 will dramatically reduce air and water pollution, improve public health, create employment and increase energy security through the reduction of imported fossil fuels.

- Clean electricity generation makes very significant contributions towards the achievement of **SDG 3** (Good Health and Wellbeing):
  - » The estimated number of prevented $PM_{2.5}$-related deaths is 1,647 from the implementation of the NDC and this rises to 2,341 in the more ambitious sustainable development (SD+) scenario.
  - » Avoided social costs from reduced $PM_{2.5}$-related mortality are estimated at USD 2.7 billion if the current clean energy commitment was to be fully implemented. This equals 41% of the national health budget for 2019.
  - » The more ambitious SD+ scenario of using 100% of Mexico's current price-competitive renewable resources results in avoided costs of USD 3.8

billion, or 58% of the current annual budget.

- Renewable electricity can be a serious driver of economic development and support the achievement of **SDG 8** (Decent Work and Economic Growth):
  - » Employment in the electricity sector could increase by 38% as a result of implementing the existing NDC target.
  - » Achieving the SD+ targets could result in an increase as high as 129%.

- Renewable electricity can also make considerable contributions to energy security and **SDG 7** (Clean and Affordable Energy):
  - » Energy savings in 2030 represent 60% of natural gas imports, 8% of diesel imports and more than 5 times the fuel oil imports compared to total 2018 fuel imports in Mexico.
  - » These values increase in the SD+ scenario to 123% (natural gas) and 9% (diesel) while fuel oil savings remain at over 5 times their 2018 level.
  - » In financial terms, natural gas savings in 2030 alone represent USD 1.2 billion in the NDC scenario, rising to over USD 2.5 billion in SD+.

Mexico's electricity sector is not only an important foundation for building economic activity and prosperity for the people of Mexico – its future development will also determine the effectiveness and ambition of the country's climate action commitment. The NDC commitment serving as a basis for this chapter is to achieve 43% of electricity generation from clean sources by 2030. The chapter focuses on the co-benefits that the transition to clean electricity generation can have on the economy, society, public health and the energy security of the country.

1 BACKGROUND: CLEAN ELECTRICITY IN MEXICO

Mexico's integration of clean electricity sources is supported by legislation and several policy initiatives. In 2014, the Energy Transition Law (Ley de Transición Energética, LTE) replaced the 2012 Law for the Use of Renewable Sources of Energy (Ley para el Aprovechamiento de las Fuentes Renovables de Energía, LAFRE). The new law set interim targets that align with the NDC for non-conventional (clean) fuels of 25% in 2018, 30% for 2021, 35% for 2024. In response to the National Strategy for Climate Change (SEMARNAT & INECC, 2013), the LTE further mandated the elaboration of a National Energy Transition Strategy. Published in 2014 and updated in 2016, the strategy establishes the objective of 50% clean electricity generation by 2050. However, Mexico's Climate Change Mid-Century Strategy (SEMARNAT & INECC, 2016) outlines that the country must decarbonize the entire electricity sector by 2050 to reach its overall emissions reduction target.

Policies were also created to accelerate the diversification of the energy mix. The fifth goal of the Energy Sectoral Program (Programa Sectorial de Energía, PROSENER) promotes the expansion of clean energy[2] and renewable energy sources, by fostering market conditions that enable the participation of different actors in renewable energy diffusion, accessing mitigation funds and establishing private-public partnerships (Gobierno de

la República Mexicana, 2013). The Special Program for Energy Transition (PETE) seeks to extend the installed capacity for clean energy. This requires a number of measures, such as improving institutional processes regarding the development of clean energy projects, enhancing institutional capacity to forecast short-term variable renewable energies, facilitating access to clean energy markets and resources by reducing financial uncertainty through guarantee funds, promoting capital access to small and medium sized enterprises (SME) and strengthening international cooperation (SENER, 2017a).

2 CLEAN ELECTRICITY FOR EMISSIONS MITIGATION

In 2016, electricity and heat generation accounted for approximately 42% of global GHG emissions (IEA, 2019). In Mexico, electricity and heat generation is the second largest source of GHG emissions after the transport sector and constitutes 18.3% of the country's total carbon dioxide equivalent (CO_2-e) emissions (SEMARNAT & INECC, 2018). Mexico's NDC acknowledges the key role that the electricity sector must play in order to achieve the country's emissions mitigation objectives and it thus features as a key component in reducing the country's emissions in accordance with the national LTE and its NDC commitment.

The NDC target of generating 43% of Mexico's electricity from clean energy sources by 2030 has a total GHG mitigation potential of 370 $MtCO_2$-e. This equates to an average mitigation of approximately 31 $MtCO_2$-e per year, constituting 15% of the total abatement required by Mexico to meet its NDC in 2030. The clean electricity NDC target has a greater GHG emissions mitigation potential relative to the other NDC measures in the electricity sector. For instance, modernizing generation plants has a total mitigation potential

[2] In the Mexican narrative, clean sources include efficient cogeneration and nuclear, in addition to common renewable, sources. Renewable energy sources include hydroelectric, wind, geothermal, solar PV, solar thermal and biomass.

of 110 MtCO$_2$-e, reducing technical losses in the electric network can mitigate 55 MtCO$_2$-e and replacing heavy fuels with natural gas amounts to only 28 MtCO$_2$-e (INECC, 2018). These numbers emphasize the importance of the clean electricity NDC measure for GHG mitigation in Mexico.

3 CLEAN ELECTRICITY AS A DRIVER OF MEXICO'S DEVELOPMENT

The change towards a clean electricity system presents an array of social, environmental and economic co-benefits and directly aligns with the primary objective of SDG 7 to "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2019, p. 8). Local economies can be strengthened through new business fields, employment creation and productivity gains. Energy independence and domestic energy security can also be enhanced (Office of the Presidency et al., 2018). Public health can be improved through better air and water quality in urban centers and a key contribution to development challenges such as poverty eradication can be made by enabling greater access to reliable and affordable electricity (IASS, 2017a).

The co-benefits shown in Figure 1 are derived from the integration of higher shares of clean energy sources in the Mexican electricity mix, according to the GIZ study 'Spinning the Web' (Office of the Presidency et al., 2018).

Figure 1: Full range of co-benefits induced by the clean electricity NDC measure (based on analysis from Office of the Presidency et al., 2018). The selection of CBs to be quantified is highlighted.

3.1 Social co-benefits

Sourcing 43% of Mexico's electricity from clean energy sources by 2030 induces potential co-benefits that can accelerate social development and contribute to overall resilience (Office of the Presidency et al., 2018). A portion of this benefit derives from substituting conventional energy sources harmful to human health with cleaner energy. Exposure to GHG emissions, including tropospheric ozone (O$_3$), nitrogen dioxide (NO$_2$), Sulphur dioxide (SO$_2$) and particulate matter (PM$_{10}$ and PM$_{2.5}$), are all associated with increased air pollution-related mortality and illness (WHO, 2019). Globally, almost 3 million people die prematurely every year from causes linked to air pollution, such as cancer, respiratory illnesses and heart disease (IEA, 2016). In particular, PM$_{2.5}$ has strong health impacts, being the cause of more than 90% of monetized social costs of air pollution (Heo, Adams, & Gao, 2016). In Mexico, between 18,000 and 31,000 deaths per year are caused by outdoor air pollution (Enciso, 2018; INSP & INECC, 2016, p. 8; Larsen, 2015; SDP Noticias, 2018), out of which 24,390 are attributed to PM$_{2.5}$ and 1,645 to ozone (CONEVAL, 2018, p. 108). Thus, increasing the share of clean electricity can significantly improve public health and limit the growth in premature deaths, by reducing peoples' exposure to emissions from conventional electricity generation.

Furthermore, electricity access is widely recognized as a key enabler for social and economic development (IASS, 2017a) which is why it is considered an important target of SDG 7. Investing in renewable electricity generation can therefore contribute to the achievement of SDG 7, stimulating economic activity and supporting the overall development of countries. It is important to note that although conventional electricity generation can still enable development, more extensive developmental (co-) benefits can be induced through renewable sources for electricity generation, including health and employment.

3.2 Economic co-benefits

A range of direct and indirect economic co-benefits can stem from expanding clean energy sources, including employment and business creation, productivity, and the incomes of individuals and businesses. Globally, the renewable energy sector is growing and as of 2017, it boasted over 10.3 million jobs (IRENA, 2018). Investing in renewable energy (RE) generates significant direct employment opportunities, far greater than those of conventional energy sources (Gioutsos & Ochs, 2017). Renewable energy investment creates between three to five times more jobs than conventional energy (Konrad, 2009; UKERC, 2014). A major share of these renewable energy jobs is located in the manufacturing and construction of facilities and power generation equipment. Some RE jobs come at the expense of jobs in the conventional energy sector. However, job gains in the renewables (and efficiency) sectors usually greatly outweigh the losses related to conventional energy (WWF, 2009).

Expanding the share of clean electricity can also contribute to energy security, by reducing the costs attributed to energy production. Energy security can include affordability, availability, acceptability and accessibility of the energy supply and furthermore includes socio-political aspects. With rapidly decreasing costs of clean electricity generation (utility-scale photovoltaic (PV) generation is pre-

dicted to have the lowest LCOE in the future in high solar regions) (Kost et al., 2018), the energy security benefits of clean electricity are becoming ever-more evident.

3.3 Environmental co-benefits

The NDC target further generates co-benefits for the environment. Increasing use of clean electricity sources ensures that inorganic resources are conserved rather than exploited, and that intact ecosystems over ground are subsequently preserved. This maintains important services for the environment, such as water purification and CO_2 sequestration by vegetation. These ecosystem services not only improve the condition of water resources but in turn contribute to improving public health. Additionally, clean electricity generation technologies such as PV and wind consume little to no water during operations, while fossil-fuel plants require large amounts of water during the different stages of energy production (IRENA, 2015). Thermal pollution from the cooling water used in conventional thermal and nuclear power plants can also have impacts on the health of local ecosystems (IASS, 2015; Kirillin, Shatwell, & Kasprzak, 2013; Yavari & Qaderi, 2018).

Clean sources of electricity are also able to reduce or eliminate the release of harmful gases associated with the combustion of fossil fuel-based resources. This contributes to improving local air quality and the condition of atmospheric basins, as well as reducing the contribution towards the formation and impacts of acid rain, affecting plants, animals, water reserves and biodiversity of the broader ecosystems exposed to them.

4 ANALYSIS OF SELECTED CO-BENEFITS OF CLEAN ELECTRICITY

4.1 Applied scenarios and selected co-benefits

The analysis in this section focuses on three key co-benefits of increasing the share of clean electric-

ity generation to 43% by 2030: Improving public health, creating jobs, and improving energy security in Mexico. Four scenarios are considered in the following analysis. These are:

1. Business as usual (BAU)
2. Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN)
3. Nationally determined contribution (NDC)
4. SD+ (REP 100)

BAU

The BAU scenario is based on 2015 BAU projections prepared for Mexico's NDC submission and extrapolates the technology shares of the Mexican electricity generation sector from the year 2015 till 2030 to meet the projected demand. The scenario is based on a model run by Centro Mario Molina (CMM).

PRODESEN

The PRODESEN scenario is based on a scenario developed by the Ministry of Energy (SENER) in their forward-looking 'National Electric System Development Program 2018-2032' report (SENER, 2018). It achieves a share of electricity generation from clean sources of 37.6% by 2030.

NDC

The NDC scenario models Mexico's NDC goal to cover 43% by 2030. The share of technologies implemented to achieve this target is based on a model run by CMM.

SD+ (REP 100)

The more ambitious scenario models 100% of the exploitable clean energy potential based on a feasibility analysis from 2016. It achieves a share of electricity generation from clean sources of 52.5% by 2030. The scenario is based on a model run by CMM.

4.2 Improving public health through clean electricity

4.2.1 Methodology

The indicator used to assess the impact of clean electricity sources on improving public health is the total avoided health/social costs from $PM_{2.5}$ emission-related mortality. This is a common indicator used for the analysis of health impacts due to its well-established link with illness and mortality. The following method was employed in order to estimate the avoided health- and social costs from $PM_{2.5}$ emissions reductions:

First, a national electricity system model belonging to CMM was used to determine the amount of electricity generation per technology, based on their installed capacities. The share of installed capacities was determined by CMM. The generation per technology was calculated for each year from 2019 to 2030, in order to meet the forecast of national electricity demand.

Then, $PM_{2.5}$ emission factors per technology were multiplied by the amount of generation per technology, giving the total $PM_{2.5}$ emissions per technology. The sum of these products gives the total $PM_{2.5}$ emissions for all electricity generation.

Finally, the total amount of $PM_{2.5}$ emissions was multiplied by established estimates of the total social costs of $PM_{2.5}$-related mortality (Heo et al., 2016), to determine the avoided health/social costs from $PM_{2.5}$ emissions reductions. The social cost of $PM_{2.5}$-related mortality ranges between 88,000 and 130,000 USD/ton $PM_{2.5}$ in the United States (Heo et al., 2016). These values were subsequently adjusted based on recent research on this topic in Mexico (Trejo-González et al., 2019), adopting the value of a statistical life (VSL) used in the Mexican-specific research, of USD 1.63 million.

4.2.2 Results

As shown in Figures 4 and 5, increasing the penetration of clean sources into the electricity mix reduces total $PM_{2.5}$ emissions from electricity generation. It is important to note, however, that even in the most ambitious scenario (SD+ [REP 100]), which reaches 53% of generation by clean sources in 2030, $PM_{2.5}$ emissions from the electricity sector still amount to 434,000 tons by 2030. This exemplifies the urgent need to replace conventional

generation with clean and renewable sources, as even gradually reducing shares of conventional generation will generate significant impacts from $PM_{2.5}$ emissions.

Figure 6 shows the potential avoided social/health costs from reduced $PM_{2.5}$-related mortality. Imple-mentation of the NDC target results in approximately USD 2.68 billion worth of avoided costs relative to BAU, by 2030. Increasing ambition to the SD+ (REP 100) scenario sees approximately USD 3.81 billion worth of avoided costs.

Figure 2: Share of electricity generation from clean sources, per year to 2030.
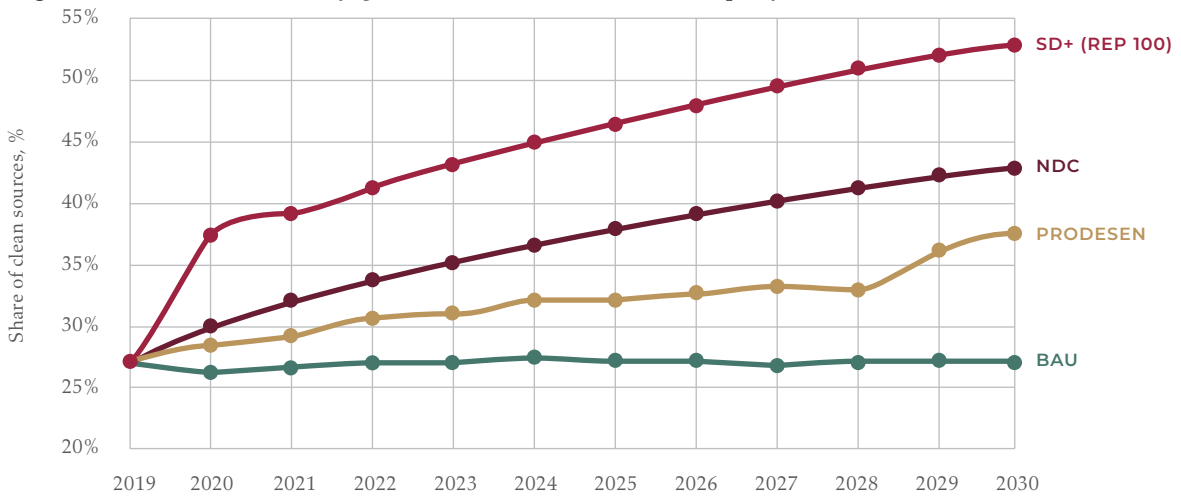
Figure 3: $PM_{2.5}$ emissions from electricity generation, per year to 2030.
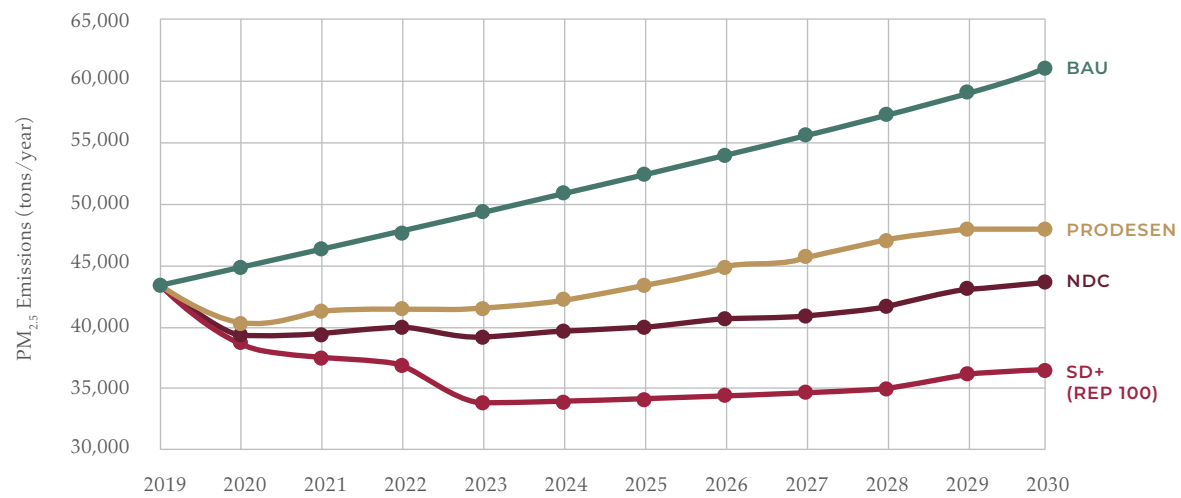
Figure 4: Total PM$_{2.5}$ emissions from electricity generation between 2019 and 2030, per scenario including reduction in %.
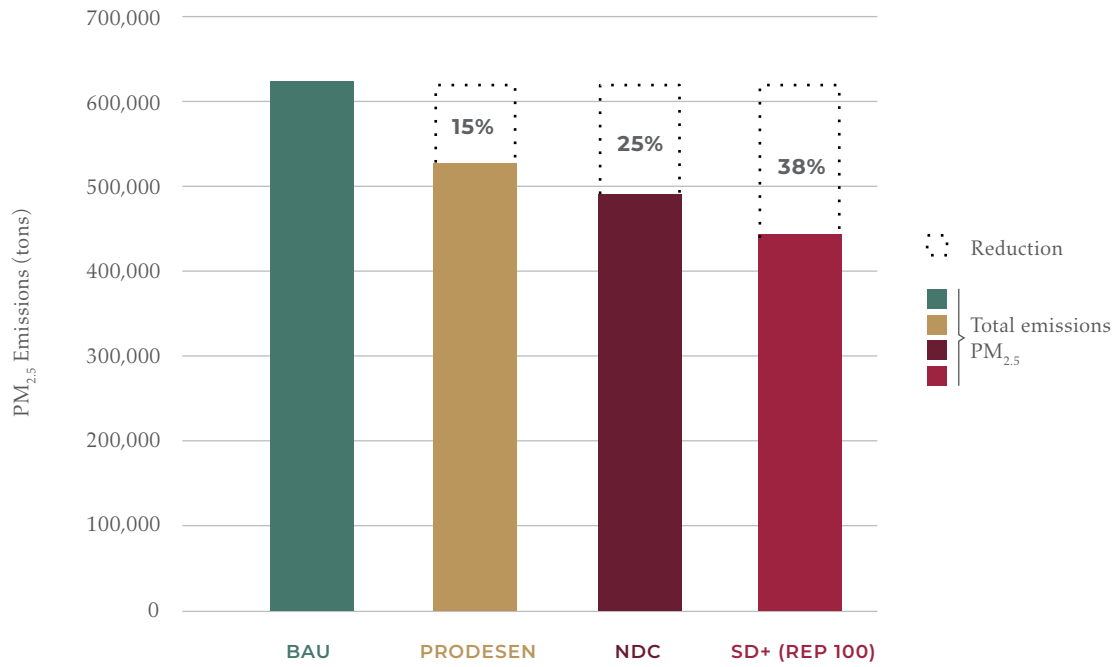
Figure 5: Total reduction of PM$_{2.5}$ relative to BAU, from electricity generation between 2019 and 2030.
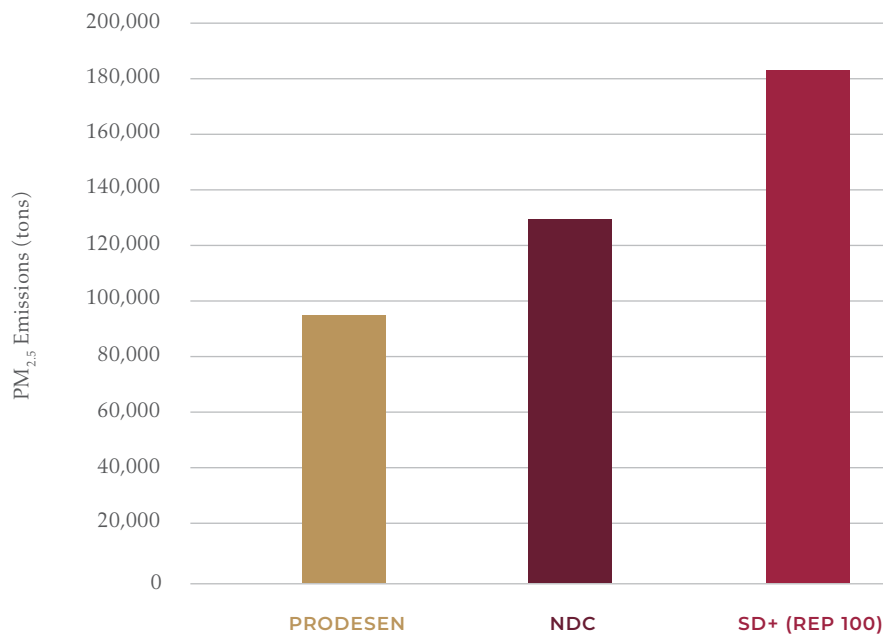
Figure 6: Total social/health costs avoided from reduced PM$_{2.5}$-related mortality, relative to BAU (2019 to 2030).
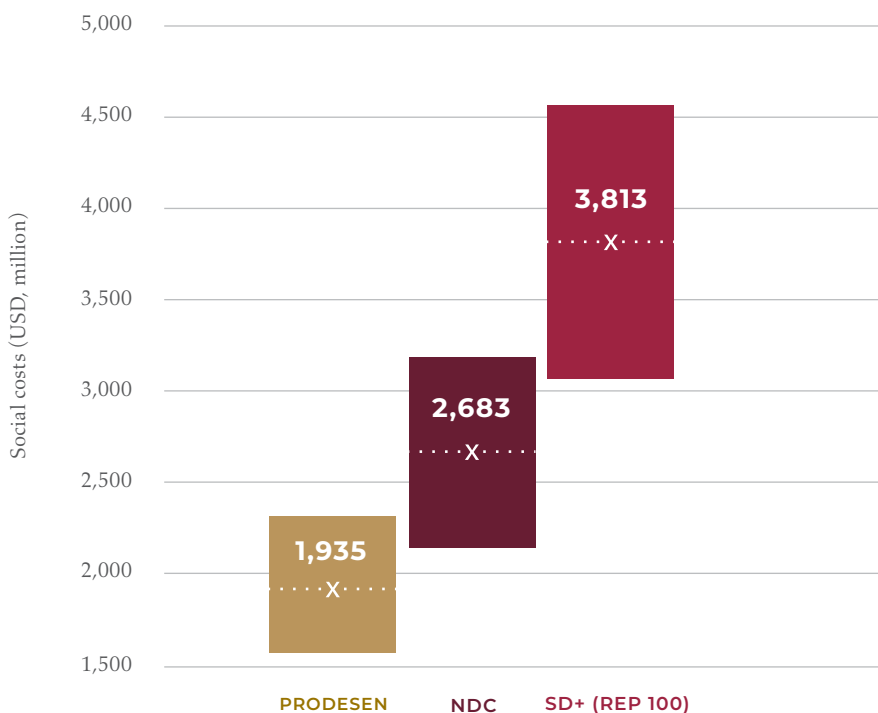
4.2.3 Discussion

The results suggest that achieving the NDC target of 43% from clean sources will result in avoided social costs from reduced PM$_{2.5}$-related mortality estimated at USD 2.68 billion. This value represents approximately 41% of the USD 6.54 billion budget that Mexico allocated to its Ministry of Health for 2019 (Diario Oficial de la Federación, 2019). Implementation of the SD+ (REP 100) scenario would result in avoided costs from reduced PM$_{2.5}$-related mortality estimated at USD 3.81 billion, representing an even larger share of the Ministry of Health's 2019 budget (58%). Increasing the share of electricity generated from clean sources can also make significant contributions towards the achievement of SDG 3 Good Health and Wellbeing. Of particular relevance are: SDG target 3.9, which aims to "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" and; SDG target 3.4, which aims to "reduce by one third pre-

mature mortality from non-communicable diseases (NCD) through prevention and treatment […]" (United Nations, 2019, pp. 4-5).
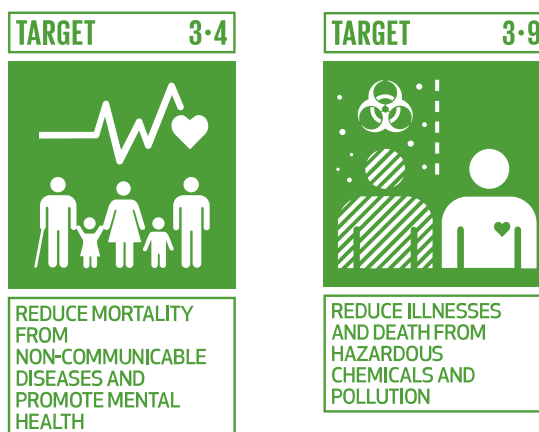
It is important to consider that these costs only represent PM$_{2.5}$-related mortality. Consideration of the wide range of illnesses that are linked to PM$_{2.5}$ emissions would likely see this number further swell.

Increasing use of clean electricity sources ensures that inorganic resources are conserved rather than exploited, and that intact ecosystems over ground are subsequently preserved.

4.3 Employment creation from clean electricity

4.3.1 Methodology

This section estimates the job creation potential of increased deployment of clean energy sources in Mexico on a national level. The indicator used to measure job creation in this analysis is the number of jobs created, in person-years. The

quantification of the employment potential of clean energy sources is based on the employment factor approach (EFA). Employment factors are technology-specific factors to estimate job impacts if multiplied with the respective installed capacity. In the quantification, only direct employment – jobs in manufacturing and installation as well as operation and mainte-nance associated with electricity generation – is considered.

Table 3: Employment factors for electricity generation technologies based on installed capacities.

Technology	Manufacturing	Installation	O&M	Sources
	[person-years/MWp]	[person-years/MWp]	[person-years/MWp]	
Hydroelectric	5.1	0.0***	5.5	(Bere, Jones & Jones, 2015)
Efficient cogeneration*	3.3	8.3	0.8	(Institute for Sustainable Futures, 2015)
Nuclear	12.1	0.0***	0.6	(IAEA, 2018)
Wind**	4.0	2.0	0.3	(Ortega, Río, Ruiz & Thiel, 2015)
Geothermal	4.0	0.0	1.7	(Dalton & Lewis, 2011)
Solar PV**	18.8	11.2	0.3	(Cameron & Van der Zwaan, 2015)
Solar thermal**	12.8	10.2	0.5	(Cameron & Van der Zwaan, 2015)
Biomass	3.5	0.0	2.3	(Dalton & Lewis, 2011)

* Average of coal, gas, biomass, geothermal technology
** EFs are averages from multiple studies
*** Included in manufacturing

The potential jobs are related to the plant lifetime for comparability within the value chain. The potential jobs are then accounted with the capacity factor to make them comparable between the different technologies.

The following formulas are used to calculate the employment impacts:

Jobs in clean energy sector
= jobs in manufacturing + jobs in installation + jobs in operation and maintenance

Jobs in manufacturing
*= MW installed per year * manufacturing employment factor * regional job multiplicator*

Jobs in installation
*= MW installed per year * installation employment factor * regional job multiplicator*

Jobs in operation and maintenance
*= cumulative capacity * O&M employment factor * regional job multiplicator*

4.3.2 Results
Figures 7 and 8 show the employment created per scenario in the period under review. The employment per year varies based on the additional capacity installed per technology. The sharp rise in employment creation seen in the SD+ scenario is attributed to the large increase in installed capacity of hydropower that is set to occur in 2019 according to the assumptions of installed capacities of that scenario.

4.3.3 Discussion
Under all explored scenarios, the number of jobs compared to the BAU scenario increase, with a gain of 16% in the PRODESEN scenario, 38% in the NDC scenario and 129% in the SD+ (REP 100) scenario. Generally, the renewable energy sector is more labor intensive compared to the fossil fuel sector, which will compensate for the expected job losses following the contraction of the fossil fuel industry. This has been observed in, e.g., China, where as a result of the 11th five-year planning 472,000 net jobs were created (IASS, 2017b). Based on the presented results it will also be the case in the Mexican context.
Electricity generation from clean sources can

Figure 7: Total employment creation from clean sources between 2019 and 2030 per year.
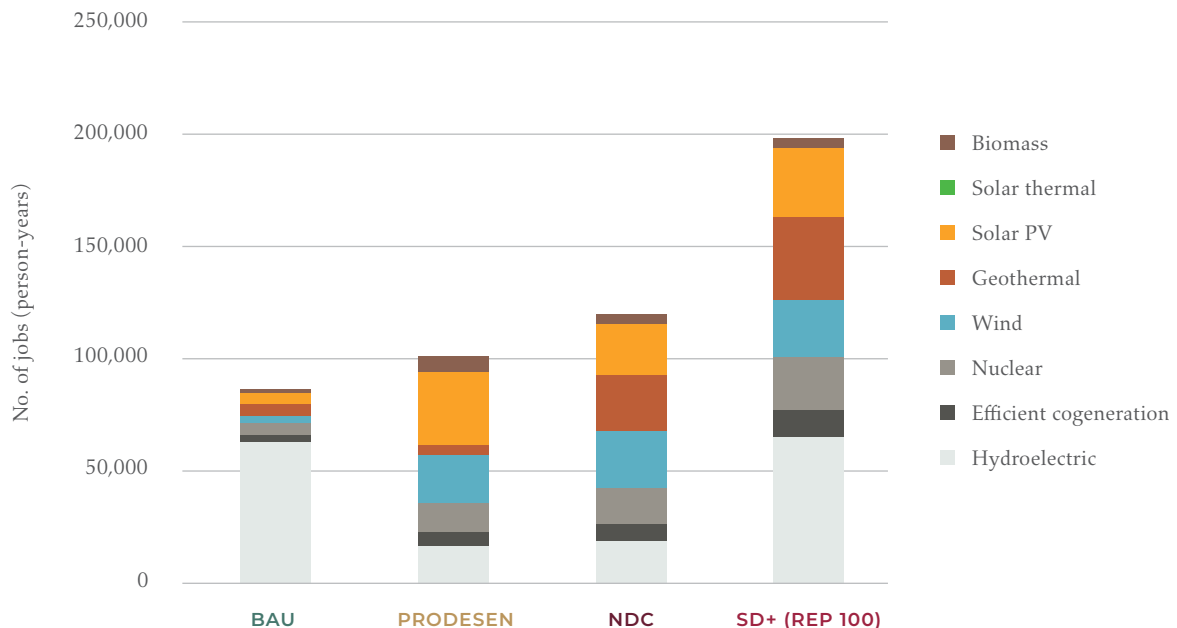
Figure 8: Employment creation from clean sources per year, 2019 to 2030.
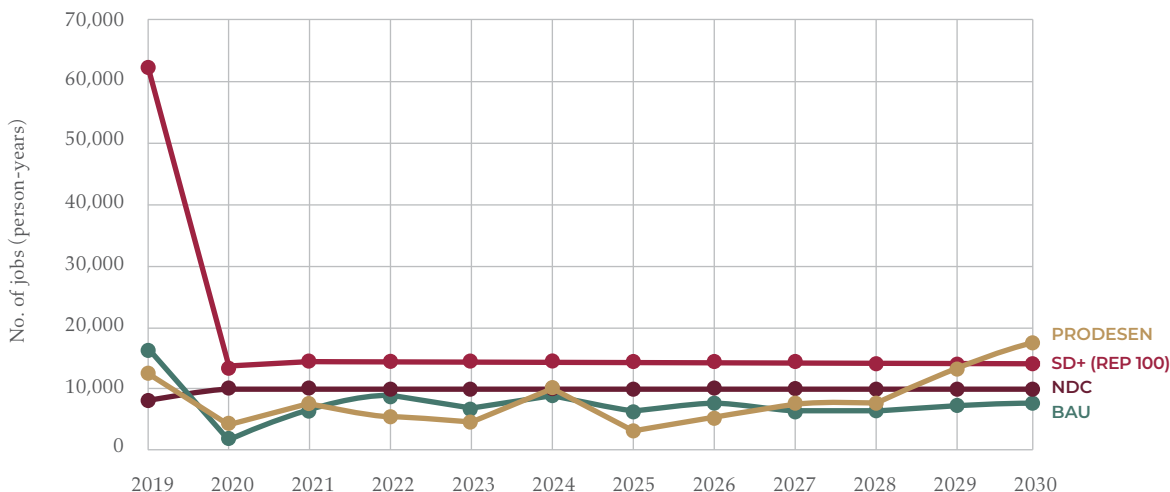
contribute to the achievement of SDG 8 Decent Work and Economic Growth. In particular, government support for innovation and growth in the clean energy sector can directly contribute to the SDG 8 target 8.3, promoting "development oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises…" (United Nations, 2019, p. 8). Furthermore, employment creation from clean energy can serve towards the achievement of SDG 8 target 8.5, to "achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities…" (United Nations, 2019, p. 8).

In relation to Mexico's overall unemployment, the jobs created through the clean energy expansion contribute to decreasing national unemployment rates. However, the percentage of such change depends on the implemented scenario. The biggest share of new employment in Mexico is expected to be in operation and maintenance. The methodology employed for this calculation asserts that the jobs created in operation and maintenance as well as in the construction of power plants will be filled by local workforce. There is, however, the possibility that international companies employ foreign staff for parts of their projects. This is particularly true for the manufacturing of the generation technologies, which are globalized and dominated by a few key market players. Solar panels, for example, are mass produced in China (Philips & Warmuth, 2019).

4.4 Improving energy security through clean electricity

4.4.1 Methodology

The indicator used to assess energy security in this analysis is the amount of reduced fuel imports in Mexico. This analysis is based on the assumption that fossil fuel consumption is reduced by replacing conventional electricity generation with clean elec-

TARGET   8·3

PROMOTE POLICIES TO SUPPORT JOB CREATION AND GROWING ENTERPRISES

TARGET   8·5

FULL EMPLOYMENT AND DECENT WORK WITH EQUAL PAY

tricity generation. The amount of saved fuel is derived using the energy savings (in GWh) of fossil fuel-based electricity generation (compared to BAU) and the respective fuel efficiency of the substituted technology. The fuel efficiencies of the substituted technologies are based on the 526 operating power plants in Mexico 2017, their efficiencies, fuel types and energy densities.

The following formulas are used to determine the amount of saved fuels:

$$Fuel\ Saved, Technology_a\ [kg] =$$

$$\frac{Energy\ saved_a\ [J]\ *\ Fuel\ share_b\ [\%]}{LHV_b^{dry}\ \left[\frac{J}{kg}\right]\ *\ Efficiency_a\ [\%]}$$

a = [Combustion plant; Fluidized bed combustion; Coal power plant; Combined cycle; Turbogas; Conventional thermal]

b = [Natural Gas; Coal; Fuel oil; Diesel]

4.4.2 Results

The total fuel savings of the PRODESEN scenario are 11% compared to the projected fuel demand for electricity generation of the country until 2030. The total fuel savings of the NDC scenario are 17% compared to the projected fuel demand of the country until 2030. The total fuel savings of the SD+ (REP 100) scenario are 28% compared to projected fuel demand of the country until 2030.

Figure 9: Total fuels used in electricity generation 2019-2030 [PJ].
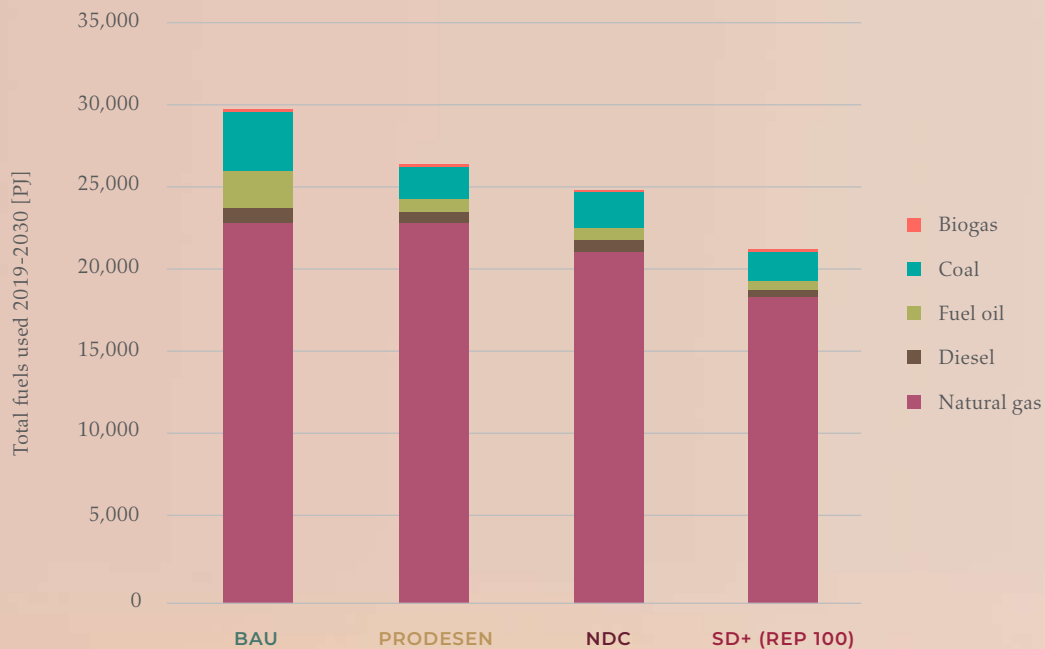
Figure 10: Total fuel savings in electricity generation 2019-2030 [PJ].
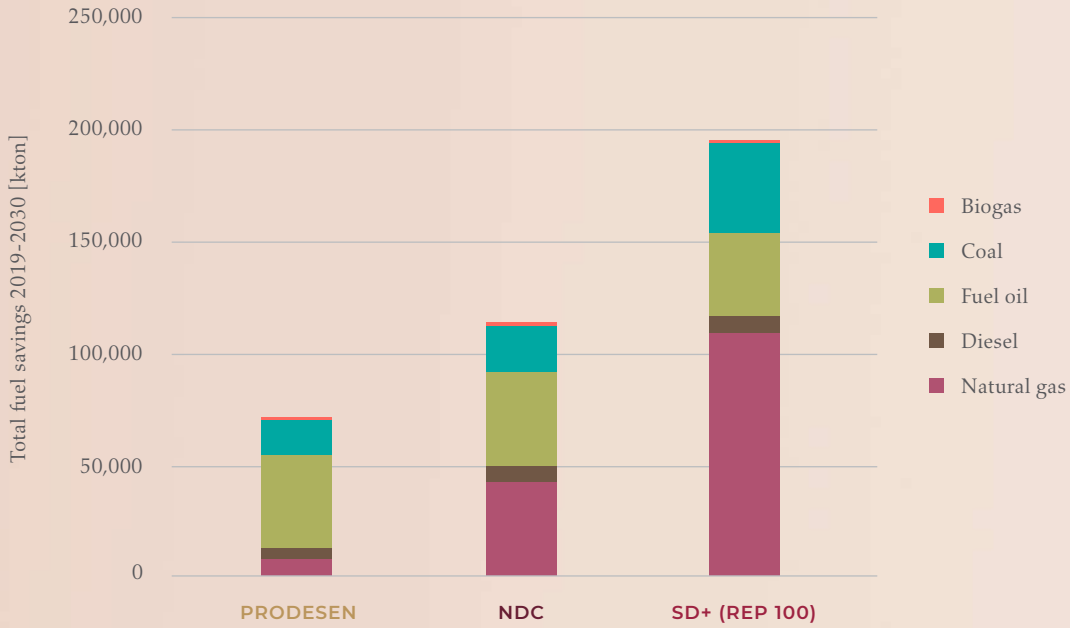
Figure 11: Total yearly fuel savings in electricity generation [PJ], NDC 2019-2030.
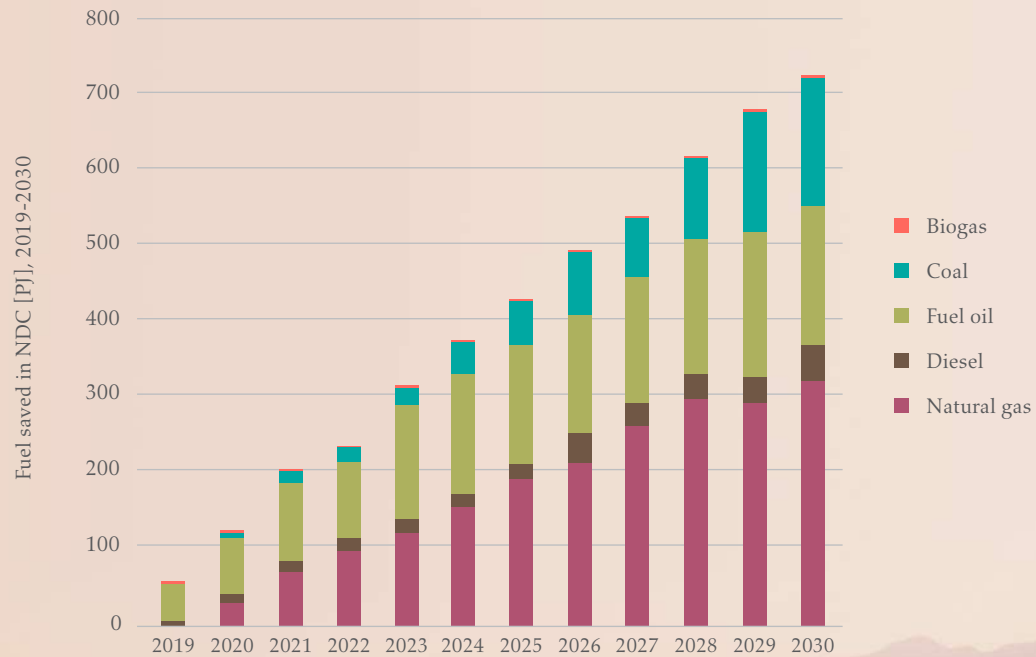
Increasing the share of clean electricity sources will reduce people's exposure to PM$_{2.5}$ emissions that entails avoided costs associated with premature deaths.

4.4.3 Discussion

As displayed in the figures, natural gas constitutes the majority of fuel used in Mexico's electricity sector. This is because in all electricity sector scenarios, approximately 50% of generation stems from combined cycle generation, which is 100% based on natural gas. Fuel oil and coal are the second most utilized fuels, followed by diesel and lastly biogas. The savings generated from the NDC scenario make a significant contribution in energy security terms: energy savings in 2030 represent 60% of natural gas imports, 8% of diesel imports and more than 5 times the fuel oil imports compared to total 2018 fuel imports in Mexico (PEMEX, 2019b). These values increase in the SD+ scenario to 123% (natural gas) and 9% (diesel) while fuel oil savings remain at more than 5 times. In financial terms, the natural gas savings in 2030 alone represent a value of USD 1.2 billion in the NDC scenario, increasing to over USD 2.5 billion in SD+ (based on 2018 import prices) (PEMEX, 2019a).

The fuel savings generated in the electricity generation sector would be accompanied by fuel savings in the transport sector, which mainly depends on fossil fuels, as fewer combustibles will need transport to conventional electricity generation plants. Furthermore, prices of renewable generation technologies are predicted to decline (Kost et al., 2018), rendering them more competitive compared to fossil fuel-based generation technology. Securing the future of Mexico's energy supply can contribute

to the achievement of SDG 7 (Affordable and Clean Energy) target 7.1, to "ensure universal access to affordable, reliable and modern energy services" (United Nations, 2019, p. 8).

5 SUMMARY AND OUTLOOK

This chapter has demonstrated the vast potential of the co-benefits associated with the NDC target of generating 43% of Mexico's electricity from clean energy sources by 2030, with emphasis on improved public health, employment creation, and energy security. In the context of public health, and based on the methodology applied above, increasing the share of clean electricity sources in each scenario will reduce people's exposure to PM$_{2.5}$ emissions by 15% in PRODESEN, 25% in the NDC scenario and 38% in the SD+ (REP100) scenario. This entails avoided costs associated with prema-

ture deaths, the value increasing with each sce-
nario: USD 2.68 billion under the NDC scenario
(41% of Mexico's Ministry of Health's 2019 bud-
get) and USD 3.81 billion in the SD+ (REP 100)
scenario (corresponding to 58% of Mexico's Min-
istry of Health's budget). However, despite the
estimated decrease in $PM_{2.5}$ emissions and asso-
ciated costs, electricity generation will still have
adverse impacts on public health.

In terms of employment creation, the expansion
of clean electricity generation will positively impact
employment in all scenarios. Under PRODESEN
it will generate 100,684 jobs (16% increase), in
NDC, 119,335 jobs (38% increase) and in SD+
(REP 100) 198,247 jobs (129% increase). Many
of these jobs, including those in operations and
maintenance as well as in the construction of pow-
er plants, are expected to employ local workers.
These results support the assertation that employ-
ment creation in the clean energy sector is labor
intensive enough to outweigh lost employment
opportunities in the fossil fuel sector.

Regarding energy security, the estimated fuel sav-
ings increase in each scenario. The savings and
subsequent improvement to energy security reduced
due to fuel imports amount to 10% in the
PRODESEN scenario, 16% in the NDC scenario
and 27% in the SD+ (REP 100).

Beyond the direct contribution to SDG 7 (Affordable
and Clean Energy) in the sustainability aspect of
the NDC target, there are synergies between its
co-benefits and several SDGs. Improving public
health aligns with SDG 3 (Good Health and
Well-being) target 3.9 on reducing the number of
deaths and illnesses from air, water and soil pollu-
tion. The co-benefit of employment creation over-
laps with SDG 8 (Decent Work and Economic
Growth), particularly regarding target 8.5 on achiev-
ing full and productive employment and the con-
tribution to energy security also ties into SDG 7.

In order to realize the full potential of the co-benefits
associated with clean electricity generation, a
number of supplementary actions must be
implemented. These include expanding grids to
avoid bottlenecks in electricity transmission,
utilizing the full renewable energy potential of the
country and developing energy storage solutions.
Building a reliable, secure and affordable renewable
energy system will be a solid foundation for
economic growth and involve intergenerational
justice by preserving limited resources for future
generations. Furthermore, electricity use habits
should be re-educated towards more economic
usage, since shifting generation to renewable energy
alone will be insufficient to meet the emissions
mitigation target of Mexico's NDC.

Figure 12: Summary of co-benefit results and links to SDGs stemming from clean electricity NDC
measure (SD Strategies, United Nations, 2019).

2
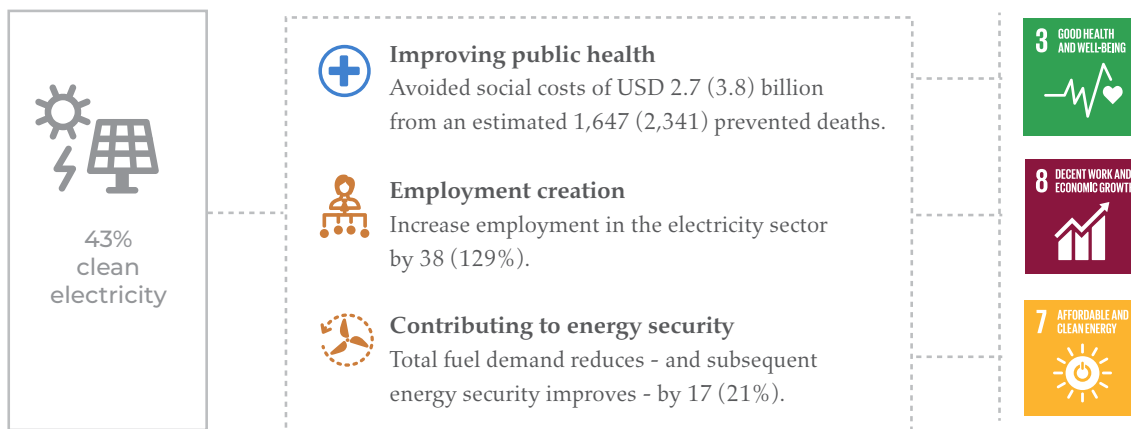
PROTECTING MEXICO'S FORESTS TO SUSTAIN NATIONAL DEVELOPMENT

KEY FINDINGS

- Reducing the current 0.2% deforestation rate to net-zero by 2030 in line with the NDC target will safeguard livelihoods, strengthen community resilience and maintain access to ecosystem services provided by Mexico's 64 million ha. It will create new employment opportunities, diversify incomes and be an important driver of water resources protection.
- Stopping deforestation will contribute directly to **SDG 8** (Decent Work and Economic Growth), as well as **SDG 9** (Industry, Innovation and Infrastructure). Preserving forests:
  - » Significantly enhances the climate change resilience of all Mexican citizens.
  - » Enables communities living in and off forests to implement business practices based on forest resources, such as eco-tourism or sustainable community-based forestry. Communities can also leverage ecosystem services such as food, building materials and shelter.
- Protecting forests also supports the achievement of **SDG 6** (Clean Water and Sanitation). It:
  - » Reduces the level of pollution in Mexico's already compromised water resources: 20% of aquifers and 30% of surface waters were significantly polluted in Mexico in 2016.
  - » Contributes to flood prevention and drought alleviation.

Beyond its cultural importance and socio-economic relevance for the livelihood of Mexico's forest communities, forests are crucial ecosystems with significant mitigation and adaptation benefits, to which deforestation represents a severe threat.

This chapter analyzes the social, economic and environmental co-benefits of achieving net-zero deforestation by 2030, with emphasis on increased community resilience, improved livelihoods and improved condition of water resources. Forests are considered a key factor in tackling climate change, due to the large capacity of capturing and storing carbon dioxide (CO_2) (Pompa-Garcia & Sigala Rodríguez, 2017). In recognizing the importance of its forest resources, the Mexican government selected net-zero deforestation by 2030 as a target in its NDC committed via the Paris Climate Agreement (Gobierno de la República de los Estados Unidos Mexicanos, 2015).

The target was selected due to its relevance for climate change mitigation and adaptation as well as the contribution to several national development objectives. Net-zero deforestation by 2030 is one of two measures the Mexican NDC lists in the area of Land Use, Land-Use Change and Forestry (LULUCF), the other one being the promotion of sustainable forest management and increased forest productivity.

1 BACKGROUND: DEFORESTATION IN MEXICO

For millennia, Mexico's vast forests have provided several social, economic and environmental benefits to its inhabitants. Beyond hosting some of the world's most biodiverse ecosystems, the forests function as a carbon sink (Pompa-Garcia & Sigala Rodríguez, 2017) and provide a broad spectrum of ecosystem services (Klooster & Masera, 2000). In total, forests support approximately 12 million people around the country, many of whom are part of indigenous communities, by providing livelihood

Figure 13: Mexico's forested areas displayed by aboveground carbon density (Cartus et al., 2014).
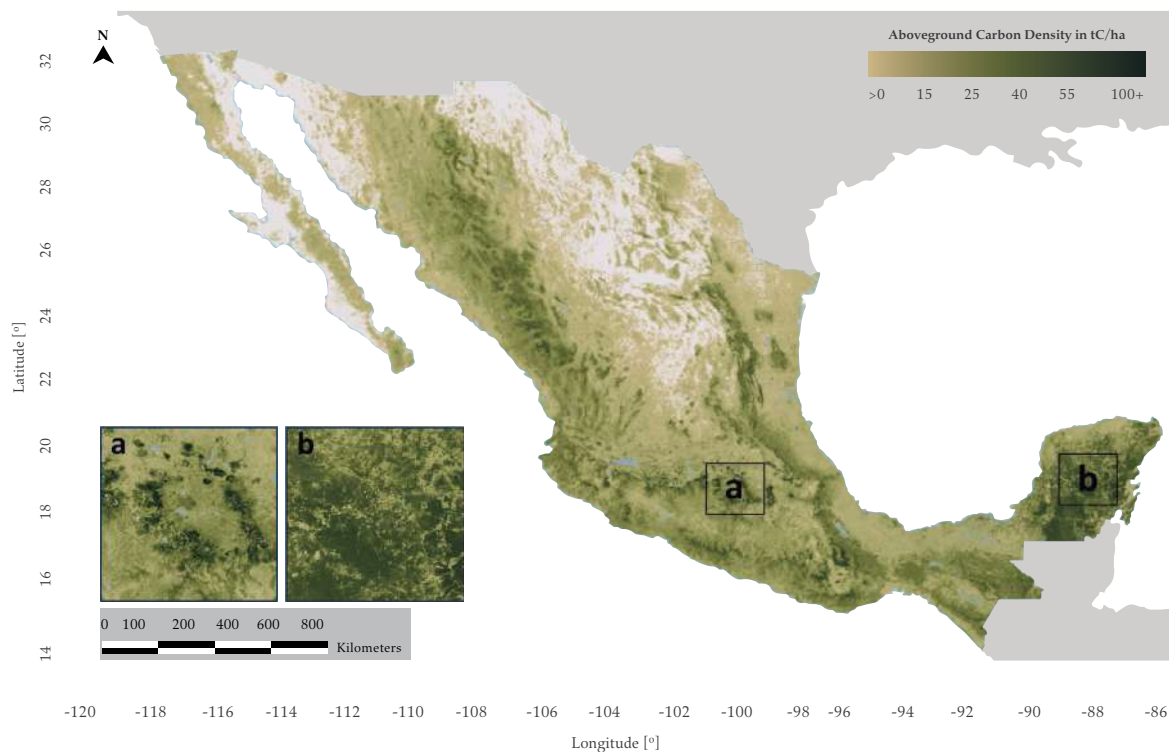
and harboring cultural heritage (Toledo et al., 2003; Klooster & Masera, 2000).

Forests cover 34.5% of Mexico's total land, translating into 64 million hectares (ha), including 34 million ha of temperate forests and 31.6 million ha of tropical rainforest (for a detailed overview, see Annex) (CONAFOR, 2017). In managing its forest assets, Mexico has pioneered policy development by instating a large-scale community-based governance system that is both legally established and locally consolidated (Bray, 2013; Cronkleton, Bray, & Medina, 2011). The system has created a foundation to sustainably capture long-term economic benefits of forests and has become a model of sustainable forest management for many Latin American countries.

Even so, deforestation is threatening Mexico's forests and the numerous services they provide. Approximately 3.72 million ha of total forest cover was lost between 1990-2015, corresponding to almost 5.3% of Mexico's forest area (FAO, 2015). While the rate of deforestation has declined in recent decades, it still amounts to an annual rate of 0.2% (Secretary of Environment and Natural Resources & National Forestry Commission, 2014). The loss of forest is highly heterogeneous, with highly biodiverse tropical forests facing far higher rates of deforestation than other forests (Goodman & Herold, 2014). If the current rate of deforestation continues, 70% of Mexico's biodiversity-rich cloud forest will be lost by 2080 (Rodríguez-Romero et al., 2018). Halting deforestation to mitigate and adapt to climate change is therefore essential.

LULUCF is considered a critical piece in realizing the Paris Climate Agreement, including the overarching objective to keep global warming well below 2 degrees relative to pre-industrial levels (UNFCCC, 2018). Forests permanently store CO_2 and continuously capture CO_2 from the atmosphere. Research suggests that global forests store over 3 trillion tons of carbon (tCO_2) and account for approximately 28% of global carbon sequestration (Climate and Land use Alliance, 2019). If forest carbon stocks were to be released into the atmosphere through deforestation, these emissions would exceed the entire estimated carbon budget of the 21st century. Considering forests' high capacity as carbon sinks, reduced deforestation and vigorous afforestation can provide nearly 37% of the total mitigation needed to meet the targets of the Paris Climate Agreement (Climate and Land use Alliance, 2019). Thus, the LULUCF sector has potential to either be a highly effective tool to abate emissions or a significant cause of such (Klooster & Masera, 2000).

In Mexico, LULUCF constitutes a considerable component of the country's efforts to curb domestic CO_2 emissions. In net terms, 32 $MtCO_2$-e were emitted in the LULUCF sector in 2013. The Mexican government expects to reduce emissions from deforestation by 46 $MtCO_2$ between now and 2030, such that in 2030, 14 $MtCO_2$ of net emissions would be sequestered (Gobierno de la República de los Estados Unidos Mexicanos, 2015). However, considering Mexico's history of deforestation, the target will need robust backing by government policy, improved forest management and social acceptance to be realized.

2 NET-ZERO DEFORESTATION AS A DRIVER OF MEXICO'S DEVELOPMENT

Net-zero deforestation is a dual-purpose measure that contributes to both mitigation and adaptation. Of all NDC sectors in Mexico, LULUCF is one of the most important to prioritize, with almost equal social and environmental benefits that extend well beyond climate action (Office of the Presidency et al., 2018, p. 37). It has potential to help realize other national development objectives and directly aligns with SDG 15, to "[…] protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss" (United Nations, 2019, p. 16). The social, environmental and economic co-benefits associated with the zero-net deforestation objective (see Figure 14) support additional SDGs and such

interlinkages are important to consider in policy design, to advance both agendas (Office of the Presidency et al., 2018).

2.1 Social co-benefits

Up to 12 million people living in forested areas may improve their livelihoods, through the services and income opportunities that a healthy forest ecosystem provides. It also provides the opportunity to diversify incomes, which in turn reduces social vulnerability to external shocks (Adger, 2006; Bray, Antinori, & Torres-Rojo, 2006). Beyond strengthening household assets, forests contribute to food security and dietary diversity among forest communities (Wildburger & Mansourian, 2015). Forest cover further improves water quality and negatively correlates with diarrheal disease prevalence (Mokondoko et al., 2016), improving public health. Generally, social vulnerability enhances climate vulnerability. Thus, socio-economic development strengthens resilience to climate change (Gobierno de la República de los Estados Unidos Mexicanos, 2015, p. 4). Preserving forests not only strengthens socio-economic capital, but also social cohesion and governance, through the community forest governance systems managing forests throughout Mexico.

2.2 Economic co-benefits

Intact forests allow local communities to leverage the multiple community forest enterprises operating across the country. Estimates suggest that hundreds of such enterprises successfully provide incomes in forest communities (Antinori & Bray, 2005), providing opportunities of employment and business creation. Whereas many CFEs are currently limited to local markets, there is potential to integrate businesses into global value chain (Antinori & Bray, 2005; Cronkleton et al., 2011) which would have positive spillovers in terms of adopting new technologies and increasing productivity (Page, 2012).

2.3 Environmental co-benefits

Net-zero deforestation has extensive environmental co-benefits beyond carbon sequestration. Preserving forest ecosystems will naturally improve ecosystem biodiversity, as the habitat of species and vegetation have space to thrive (FAO, 2018). Further, forest root systems provide slopes with natural infrastructure that holds soil in place, prevent erosion and help maintain high soil quality, by absorbing water and transpiring it into the atmosphere which effectively regulates the moisture

Figure 14: Full range of co-benefits induced by the net-zero deforestation NDC measure (SD Strategies, based on analysis from Office of the Presidency et al., 2018). The selection of CBs to be quantified is highlighted.

content of the soil and prevents it from becoming overly sodden (Bathurst, Moretti, El-Hames, Beguería, & García-Ruiz, 2007). Forests also improve the quality of water resources and atmospheric basins (Fletcher & Gartner, 2017).

3 ANALYSIS OF SELECTED CO-BENEFITS OF NET-ZERO DEFORESTATION

3.1 Applied scenarios and selected co-benefits

The analysis and discussion in this section focuses on the following co-benefits: improving livelihoods and community resilience[3], and improved condition of water resources. Each co-benefit is analyzed through the application of three different scenarios relating to the future condition of Mexico's forests: business as usual (BAU) which assumes continued deforestation at the current rate of 0.2%, an

NDC-compatible scenario, i.e., net-zero deforestation by 2030, and a more ambitious scenario referred to as sustainable development plus (SD+) assuming net positive afforestation or re-forestation.

3.2 Improving livelihoods and community resilience through forest protection

Beyond its important climate mitigation and adaptation benefits, successful implementation of the net-zero deforestation commitment can strengthen livelihoods and community resilience (Office of the Presidency et al., 2018). Forest ecosystems are intimately connected to the prosperity of people that live in and around them. Due to inconsistent

[3] The co-benefit of improving livelihoods and community resilience was adapted from two co-benefits: reduced vulnerability and increased resilience.

Figure 15: Degree of climate change vulnerability in Mexico's municipalities (Gobierno de la República de los Estados Unidos Mexicanos, 2015).
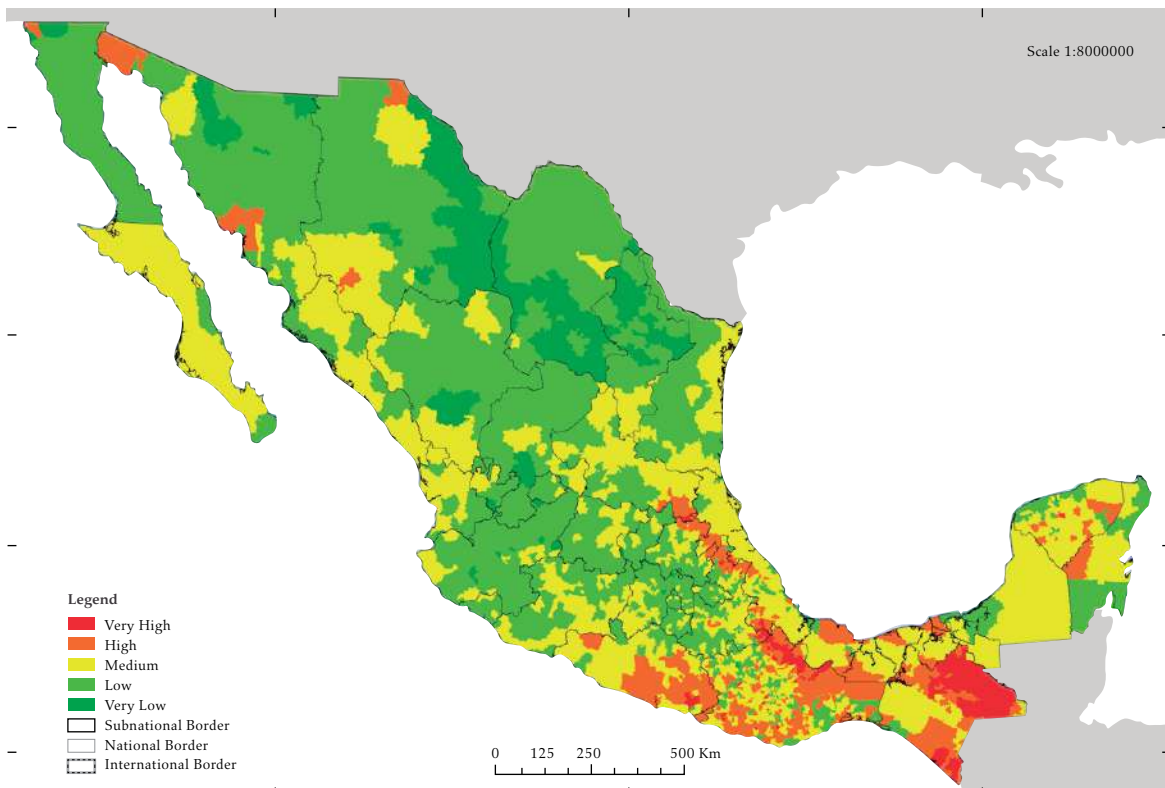
access to public services and the private labor market, many communities depend on the capacity of forests to provide economic, natural and cultural services (Comisión Nacional para el Desarrollo de los Pueblos Indígenas, 2015). For instance, forests provide livelihoods for over 9000 communities through community forest management (CFM) (Hodgdon et al., 2013). Furthermore, Mexico has identified the most vulnerable municipalities in the country and many of these are located in forest areas (Gobierno de la República de los Estado Unidos Mexicanos, 2016). Several of these forests have high carbon stocks where deforestation generates high emissions per ha (Cartus et al., 2014).

3.2.1 Methodology

The heterogeneity of Mexico's geography and forest landscape complicates aggregate estimates of deforestation and associated social, economic and environmental implications. Certain forests may be more productive, harder to replace or more valuable than others. It is therefore insufficient to merely analyze total tree cover, since a hectare of deforested rainforest could technically be replaced by a hectare of oil palms, which would not provide the same benefits in terms of ecosystem services,

biodiversity preservation and carbon sequestration. The deforestation rates of similar forest ecosystems are further estimated at different levels, as drivers of deforestation vary across locations and communities. Considering the absence of robust valuation methods regarding livelihoods and community resilience as well as a shortage of data in this area, it is hard to produce precise indicators for the impact of reduced forest loss on these important co-benefits. Therefore, this chapter employs qualitative analysis and provides numbers wherever possible. Further details on general methodological constraints are provided in the Annex.

Improving livelihoods and community resilience entails reducing a community's vulnerability, which can be defined as the "exposure, sensitivity and adaptive capacity" (Office of the Presidency et al., 2018, p.25) to overcome a given hazard or phenomenon. Both structural socio-economic factors and infrastructure-related factors affect the vulnerability of communities and individuals, favoring a holistic analysis of forests' contribution to resilience (Office of the Presidency et al., 2018). Resilience, in turn, refers to a community's capacity to "anticipate, reduce and recover from the effects of an adverse event in a timely and effective manner"

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Deteriorating local resources will increase poverty, fuel urban migration and decrease food security.

(Office of the Presidency et al., 2018, p.25). Resilience is analyzed here along with both technical and socio-economic factors. Improved livelihoods and community resilience include economic resilience, that is, the means to recover from an external shock, as well as environmental resilience, which refers to a community's access to resources, information, and physical protection.

3.2.2 Results

The following subsections discuss the contributions and implications associated with livelihoods and community resilience in each selected scenario.

BAU Scenario

Whereas land change through deforestation may lead to short-term economic benefits, it is by no means certain that such benefits will be captured by local communities. It is also likely to deteriorate ecosystems, local livelihoods and community resilience in the long term. Under BAU, all types of forests will suffer from continuous deforestation, with evergreen forests being one of the most endangered forest systems by 2050 (Mendoza-Ponce, Corona-Núñez, Galicia, & Kraxner, 2018). Generally, the current deforestation rate may negatively affect local incomes and access to resources, such as wood and timber production, non-timber forest products (NTFP), tourism revenue, PES and water management (Klooster & Masera, 2000). In terms of environmental quality and the ecosystem services crucial to community welfare, the BAU deforestation scenario will degrade Mexico's outstanding biodiversity hotspots, contribute to soil erosion and induce hydrological changes in critical watersheds (Klooster & Masera, 2000). Overall,

deteriorating local resources will increase poverty, fuel urban migration and decrease food security (Mendoza-Ponce et al., 2018), rather than producing co-benefits that contribute to sustainable and socially inclusive development.

NDC-compatible scenario

Achieving net-zero deforestation is expected to generate several development benefits that contribute to improved livelihoods and community resilience across the country. By utilizing forest resources sustainably, rather than converting land for the purpose of agricultural expansion, communities may diversify incomes and decrease their socio-economic vulnerability. It can be conducted in a number of ways, for instance through Payments for Ecosystem Services (PES), where communities are paid to preserve forests (Pagiola, Arcenas, & Platais, 2005). Such programs acknowledge that many rural landowners are confronted by poverty and low income, to which these payments can improve their livelihoods and resilience through income diversification. Mexico's PES programs have enrolled over 4 million hectares of land and were compensating 7,350 property owners with over $15.9 million Mexican pesos by 2017 (Alatorre-troncoso, 2014; Rodríguez-Robayo & Merino-Perez, 2017). Also, they reduced deforestation by as a much as 40% in high risk areas, had a neutral or positive effect on social capital and increased investment in communal infrastructure by 20-25% in communities (SEMARNAT, CONAFOR, & World Bank, 2017). Detailed information regarding PES is provided in the Annex. Another opportunity is to maximize the potential of Mexico's CFM and its associated CFEs, which

govern over 60% of Mexico's forest resources (Hodgdon et al., 2013). CFM has proven effective to curb deforestation and often includes traditional methods less inclined to deplete environmental resources (Toledo et al., 2003). By leveraging global value chains (GVC), community forest enterprises can capture synergies between local and global development interests. Such development is observed throughout the global south and allows local actors to access global markets (FAO, 2009; Sutton, Jinhage, Leape, Newfarmer, & Page, 2016). An example of successful vertical integration is found in the Ixtlán de Juárez community. Managing over 21 000 ha of community forests, the community forest enterprises produce furniture certified by Rainforest Alliance. In fact, the community forest enterprises now compete with Chinese manufacturers (Cronkleton et al., 2011). Other examples of economic diversification observed in forest communities include eco-tourism, transport, hydrological services and water-bottling (Klooster & Masera, 2000; Cronkleton et al., 2011).

Forests also provide communities with foods and resources. In fact, research suggests that forest foods make up varying parts of rural communities' diets, through, e.g., fruits, fungi and bush meat (Wildburger & Mansourian, 2015; Rowland et al., 2017). Forest foods may be especially effective in mitigating seasonal food scarcity, as a complement in the events of crop failure or fluctuating agricultural commodity prices (Bhaskar, Christoph, & Mansourian, 2015). Hence, limiting the deforestation rate to net-zero

Box 1: The importance and value of mangroves.

CASE STUDY: MANGROVES

Mangroves represent less than 1% of the total amount of forest in Mexico. However, their contribution to climate change mitigation, adaptation and the wellbeing of local communities is considerable. They can sequester 3-4 times more CO_2 per hectare than most terrestrial ecosystems, storing as much as 1000 Mg c ha-1 compared to 200 and 300 Mg c ha-1 for tropical and temperate forests respectively. Thus, Mexico's mangroves can capture 0.78 gigatons (Gt) of CO_2 from the atmosphere annually, rendering carbon storage capacity very high. Conversely, mangrove deforestation releases high CO_2eq. In terms of adaptation, mangroves protect coastal communities from tropical storms by providing natural barriers against storm surges (Zhang et al., 2012). Even 40-50 cm/km of forest can reduce the impact of storm surges (McIvor et al., 2012).

Beyond carbon sequestration and disaster risk reduction (DRR), positive net mangrove afforestation would provide more income and food harvesting opportunities to communities. Despite limited research, there are broad trends pointing to their importance to human welfare. They provide direct use value, including provision of firewood, timber, fishing and other resources, as well as indirect use value including services indirectly obtained from mangroves, such as healthy fisheries, erosion protection, endemic biodiversity conservation as well as cultural value (Rizal et al., 2018).

Studies of mangroves in Indonesia suggest that direct use value can vary from USD 19.42 – 1,687 per ha and indirect use value ranges from USD 637 – 24,000 per ha (Rizal et al., 2018). Applying these figures, the direct use value of mangroves in Mexico for the period between 2019 and 2030 is estimated at USD 0.09 – 7.8 billion. The indirect value is estimated at USD 2.9 – 111 billion. The wide range of these value estimates demonstrates the need for further research on the value of mangroves. They have been deforested at high rates, with an estimated loss of over 80,850 hectares, about 10% of total mangrove forest since 1970 (Osland et al., 2018) which can be traced to land use change via agriculture, shrimp farming, coastal development and over-exploitation of fishing and timber. Although some areas now display a net increase (FAO, 2015), efforts will be needed to ensure the health of these ecosystems.

can contribute to addressing food scarcity through the supply of forest foods.

SD+ scenario: net-positive afforestation

Afforestation means taking more carbon out of the atmosphere than in previous years, resulting in a positive climate effect. In a scenario of net-positive afforestation, the development gains discussed in the NDC-compatible scenario can be captured on a larger scale. The efficiency of afforestation varies across geographies, with certain forest lands creating greater benefits than others. For instance, converting degraded agricultural land to diverse forest ecosystems generates large benefits both in terms of carbon stock and livelihoods. It is therefore important to strategically plan reforestation efforts to gain maximal benefit. Forests' recovery time is another important aspect. For instance, mangrove ecosystems are proven to recover remarkably fast, generating high impact with relatively low costs.

3.2.3 Discussion

This section has identified several co-benefits that forests provide for Mexican communities. However, there is an urgent need to deliver more precise assessments of the potential benefits. Future research should, therefore, focus on gathering data regarding the potential economic value of the community forest enterprises industry, exploring potential niche markets where such entrepreneurs possess a competitive advantage, and mapping the extent of forest food consumption in households. Some of Mexico's poorer states, such as Guerrero and Chiapas, expect population growth without associated economic growth (Mendoza-Ponce et al., 2018). Leveraging the potential co-benefits can help avoid further degradation of forest resources and increased poverty. Especially the development of sustainable community forestry displays potential scalability that could substantially improve livelihoods and community resilience by providing employment and revenue streams for asset building and socio-economic development.

Social vulnerability decreases resilience to climate change and climate variability (Gobierno de la

República de los Estados Unidos Mexicanos, 2015). Therefore, it is important not only to consider the more technical aspects of the co-benefits, but also to capture and facilitate socio-economic dimensions. Holistic resilience-building, including social, economic and environmental improvement, will be necessary in Mexico's most vulnerable forest communities to prevent the negative implications identified under the BAU deforestation scenario.

As mentioned in section 3, significant synergies exist between Mexico's NDC agenda and the SDGs. Improving livelihoods and community resilience directly contributes to achieving SDG 8 (Decent work and economic growth). For example, strengthening community forest enterprises and their integration into global value chains supports the SDG target 8.2 on "[…] achieving higher levels of economic productivity through diversification, technological upgrading and innovation […]" (United Nations, 2019, p. 8). If sustainable community-based forestry is fully realized, it has the potential to de-couple community development and environmental degradation, thus contributing to the achievement of SDG target 8.4, which strives to "[…] improve global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation […]" (United Nations, 2019, p. 8). Community forest enterprises development further benefits SDG 9 on industry, innovation and infrastructure. In particular, it supports SDG target 9.3, which seeks to "[…] increase the access of small-scale industrial and other enterprises, in particular in developing countries […] and their integration into value chains and markets" (United Nations, 2019, p. 9).

TARGET 8·2 — DIVERSIFY, INNOVATE AND UPGRADE FOR ECONOMIC PRODUCTIVITY

TARGET 8·4 — IMPROVE RESOURCE EFFICIENCY IN CONSUMPTION AND PRODUCTION

TARGET 9·3 — INCREASE ACCESS TO FINANCIAL SERVICES AND MARKETS

3.3 Forests' contribution to improving water resources

The health of water resources is crucial to the welfare of society. In Mexico, forest ecosystems are key contributors in the hydrological system and critical in preserving and restoring potable water sources. Central functions include the regulation of water supply, quality improvement through filtration and cloud generation through evapotranspiration (Fletcher & Gartner, 2017). Due to the complexity of these processes, they are often overlooked and undervalued (FAO, 2018). This section will explore how net-zero deforestation can contribute to improving the condition of water resources.

Mexico has 37 hydrological regions in which there are 757 water sources, where 649 are available for use. It has approximately 451,585 cubic hectometers (hm^3) of renewable water, which translates to 3,656 m^3 of renewable water resources per capita per year (CONAGUA, 2018b). Much of this water originates from rivers, lakes and aquifers across the country, which are fed by rainfall. Although Mexico has significant hydrological resources, the distribution of population and water is inverse, with the majority of water-intensive industries and 77% of the population located with access to only 33% of national renewable water resources (CONAGUA, 2018b).

3.3.1 Methodology

A growing body of research point to strong linkages between the quality of hydrological services and forests, which also formed the basis for Mexico's implementation of the PES program for Hydrological Ecosystem Services. However, the lack of Mexico-specific data and the heterogeneity of ecosystems complicates the modelling of forests' impact on water resources. Whereas many aspects of the hydrological cycle and the exact role of forests is poorly understood (Munoz-Pina, Guevara, Torres, & Brana, 2006; Werth & Avissar, 2005), local studies have measured the change of water pollut-

ants under afforestation (Madrigal, Van Der Zaag, & Van Cauwenbergh, 2018; Mokondoko, Manson, & Pérez-Maqueo, 2016). However, it is not enough to aggregate national estimates based on such indicators. Therefore, this section draws on previous research in Mexico and beyond to identify the main ways in which net-zero deforestation can contribute to improving the condition of water resources. However, further research is needed to quantify the exact scope of these co-benefits.

3.3.2 Results

The following sections discuss the implications of each selected scenario on the condition of water resources.

BAU scenario

The current deforestation rate of 0.2% annually implies a decreasing amount of forest close to water resources. Hence, the natural protection against water pollutants will decrease simultaneously (Anbumozhi, Radhakrishnan, & Yamaji, 2005). Climate change, environmental degradation and El Niño[4] already stress water resources, which are further exacerbated by the imbalance of supply and demand (CONAGUA, 2018b). Aside from climate-related stressors, many of the most reliable water resources are polluted. Poor water quality is closely tied to high public health costs and impacts the poorest members of society disproportionately (Mokondoko et al., 2016). It was estimated in 2016 that 20% of aquifers and 30% of surface waters were significantly polluted in Mexico (Madrigal et al., 2018). Deforestation also contributes to soil erosion and hydrological changes in critical watersheds. Some 16.6% of Mexico's territory (32.5 million ha) is severely eroded (Klooster & Masera, 2000). Lost soil deposits in dams, rivers, lakes, and coastal wetlands has repercussions on navigation, energy production, fisheries, and food control (Klooster & Masera, 2000).

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[4] El Niño is a non-cyclic weather phenomenon that leads to anomalies in the normal weather pattern. It can cause severe storms and rough droughts every five to ten years.

NDC-compatible scenario

Successful implementation of net-zero deforestation can improve the condition of water resources in Mexico. Forest cover in riparian zones minimizes the amount of sediment, pollutants and chemicals that enter the water stream, therefore being an important ecosystem component for healthy water resources (Dittrich, Ball, Wreford, Moran, & Spray, 2018). The forest's absorption capacity is especially efficient when grown at a width of 50 meters or more (Anbumozhi et al., 2005). It was found that riparian zone forest cover on the Antigua River watershed significantly decreased the prevalence of E. coli bacteria in the water, an area covering nearly 32% of all surface flow in Mexico (Mokondoko et al., 2016). A similar study of the Filobobos River demonstrated that conserving riparian zones and forest cover upstream of watersheds positively impact the water quality compared to downstream zones, in terms of E. coli, nitrogen (N_2) and phosphorous concentrations (Rodríguez-Romero et al., 2018).

Forests also contribute to flood prevention, by absorbing water and releasing it over time. While studies of this phenomenon in Mexico are scarce, research on flood attenuation capacity of forests in Slovakia suggests that deforestation increased surface runoff by 38.8% and that deforested watersheds had peak water discharges that were 58% higher than their forested counterparts (Hlásny et al., 2015). A recent cost-benefit analysis (CBA) of British afforestation in riparian zones further found that any tested scenario was worthwhile implementing when considering the co-benefits from flood regulation and other ecosystem services (Dittrich et al., 2018). Considering the potential contributions to flood attenuation capacity in Mexico, the topic would benefit from further research. Conversely, forests can reduce the amount of water lost from surface runoff and excess discharge, effectively saving and economizing snow and glacial melt as well as regular rainfall over a longer time span. This service is particularly important in dry areas with sparse rainfall that depend on

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the natural water regulation mechanism. For example, high elevation forests store large amounts of water that helps feed lower-elevation areas with a steady stream of water, thus alleviating drought conditions (FAO, 2018).

SD+ scenario

In an ambitious scenario, the aforementioned contributions to the improved quality of water resources can be implemented on a larger scale. In a scenario of expanding afforestation, riparian zones should be prioritized due to the dual impact on water quality and carbon sequestration.

3.3.3 Discussion

It is clear that forests will be one of Mexico's greatest assets in combating climate change and ensuring continued vitality of the land. That is also true for improving the quality of water resources, as forest ecosystems provide numerous water-related services. Based on the discussed material, riparian zones seem to have high potential for improving the state of Mexico's water resources through strategic afforestation and reforestation programs. Compared to engineered approaches with high initial costs and short-term specified benefits, nature-based solutions (NBS) such as afforestation are increasingly considered cost-effective, due to the relatively low costs and the multiple co-benefits provided by ecosystem services (Dittrich et al., 2018; Royal Society, 2014). The drawback of NBS is the weak short-term contribution. Therefore, hybrid approaches combining engineered approaches and NBS would be most effective in maximizing benefit and minimizing costs of improved water quality (Dittrich et al., 2018; Royal Society, 2014). As Mexico is regularly exposed to droughts and flooding, it could consider the use of afforestation to mitigate the worst impacts of both phenomena, as described in the NDC-compatible scenario analysis. Further research could be conducted in regions that are frequently flooded or exposed to droughts, to see if afforestation is an appropriate method for adaptation.

Furthermore, net-zero deforestation can contribute to the achievement of SDG 6 on clean water and sanitation. In particular, sustaining and extending healthy forest ecosystems in riparian zones supports SDG target 6.6, to "protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes" (United Nations, 2019, p. 7).

Especially the SD+ scenario, implementing strategic afforestation in riparian zones, constitutes considerable opportunities to improve the condition of water resources and ensure healthy water-related ecosystems.

4 SUMMARY AND OUTLOOK

This chapter has analyzed selected co-benefits of the NDC measure 'net-zero deforestation by 2030'. The selected co-benefits include improved livelihoods and increasing community resilience as well as improving the condition of water resources. Regarding livelihoods and community resilience, net-zero deforestation contributes to income-generation, food security and protection against hydro-meteorological events, contributing to SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). In terms of improving quality of water resources, forests help prevent pollution from entering streams and springs and support flood prevention and drought alleviation, contributing to SDG 6 (Clean Water and Sanitation). Implementing measures such as afforestation under

the SD+ scenario naturally entails costs. However, the strong global benefits of carbon sequestration can be leveraged to obtain international funding for forest conservation, such as by the Green Climate Fund. Furthermore, as the NDC agenda and associated co-benefits are relevant to achieving several SDGs, Mexico may coordinate these processes to maximize resource efficiency and minimize costs. It is important to emphasize that the co-benefits discussed in this chapter are only potential. To realize them, adequate regulation, incentives and budget allocation are necessary. It is further important to strengthen partnerships in the coordination and implementation processes, such as public-private and inter-sectoral partnerships. Going forward, it is important to progress the

valuation and quantification of the NDC agenda's social, economic and environmental co-benefits, in order to adequately allocate resources in mitigation and adaptation processes. Especially the areas of afforestation of riparian zones and mangroves as well as CFE business development would benefit from further research. Mapping current rates of riparian zone deforestation and most exposed areas, synchronized with data on water quality, could provide better understanding of the relationship between riparian zone forests and water quality. Regarding CFE business development, it could be useful to further explore potential niche markets for forest goods and services in the context of CFEs as well as their potential contribution to the local and national economy.

Figure 16: Summary of co-benefit results and links to SDGs stemming from net-zero deforestation NDC measure.

3

TREATING WASTEWATER FOR MEXICO'S PROGRESS

KEY FINDINGS

- In addition to several other development benefits, achieving the NDC target of treating all municipal wastewater in cities with more than 500,000 inhabitants will significantly improve Mexico's climate resilience by reducing the need for freshwater withdrawals for non-potable water needs.

- Increasing wastewater treatment coverage and reusing properly treated wastewater can be a key element of social and economic development. It improves the quality of water resources, contributes to human and ecosystem health, and improves energy security.

- The percentage of wastewater treated is a key indicator of **SDG 6** (Clean Water and Sanitation). Increasing wastewater treatment capacity in accordance with Mexico's NDC in this sector would support the country in meeting the SDG target of halving the percentage of wastewater not treated – although fully accomplishing that target would require greater efforts.

- Meeting the wastewater NDC and reusing 80% of treated wastewater will result in 4.6 billion cubic meters of wastewater available for non-potable water needs. This amount increases to 7.5 billion cubic meters under the more ambitious SD+ scenario.

- The treatment of wastewater and avoidance of its release into Mexican water bodies will also entail benefits to the health of people and ecosystems, contributing to the achievement of **SDG 3** (Good Health and Wellbeing):
  - » 1.34 million tons of organic pollutants will be prevented from being dumped into surface water and soil under the current NDC.
  - » 2.24 million tons would be prevented from release under the SD+ scenario.

- Wastewater can be processed as a source of renewable energy, thus contributing to **SDG 7** (Clean and Affordable Energy). Wastewater processing could produce enough biogas-based electricity to supply the needs of at least 50,000 Mexican households.

The treatment of wastewater is not only a prerequisite to ensuring public sanitation and people's health but is also critical to increasing resilience of human settlements in the face of global warming and, if neglected, can significantly contribute to increasing carbon emissions.

This chapter analyzes the development benefits of implementing wastewater treatment measures in Mexico, such as treating more wastewater for reuse, reducing freshwater withdrawals for agricultural and other uses, and reducing water and soil pollution from discharge of untreated wastewater. In particular, it looks at the following co-benefits: improving livelihoods and community resilience, improving the condition of water resources, as well as advancing energy security. As improved livelihoods and increased community resilience are closely interconnected, they will be discussed in the same subsection. The target serving as the basis of the chapter's analysis constitutes Mexico's NDC measure, to "[…] guarantee urban and industrial waste water treatment, ensuring quantity and good quality of water in human settlements larger than 500,000 inhabitants and to monitor their performance" (Gobierno de la República de los Estados Unidos Mexicanos, 2016, p. 8). For the purpose of this study, the NDC target is interpreted as treating all municipal[5] wastewater collected in localities with more than 500,000 inhabitants. The core of the analysis is quantitative; however, when quantitative estimates are not possible, qualitative analysis is applied, using figures from specific cases as indication of potential benefits.

1   BACKGROUND: STATUS OF WASTEWATER TREATMENT IN MEXICO

Mexico has made great strides in the provision of potable water and sanitation over the past three decades. However, progress in advancing wastewater treatment has been slower. Figure 17 compares Mexico's performance on these metrics compared to the regional and global averages. As shown in the figure, in the area of water, sanitation

and sewerage, Mexico exceeded the Latin American and global averages already in 2017, with 95.3% of the population having access to potable water and 92.8% with access to sanitation and sewerage. However, the country falls below the global average regarding the treatment of wastewater. As of 2017, only 63% of municipal wastewater generated in the country was treated, compared to the global average of 68%.

Mexico currently has 2,526 Wastewater Treatment Plants (WWTP), with capacity to treat 63% of the total municipal wastewater produced in 2017 (CONAGUA, 2018b). 92.8% of Mexico's wastewater is drained, but not always disposed through the public sewerage system. In fact, it can be discharged without any treatment to creeks, lakes, rivers, or the ocean (IMTA, SEMARNAT & GIZ, unpublished)[6]. Water quality data from Mexico's Water Atlas, shown in Figure 18, illustrates that poor water quality is concentrated in the country's most populated areas (CONAGUA, 2018a). Within Mexico, there are 42 localities with a population of 500,000 or more and 12 additional localities are projected to exceed the mark by 2030 (all localities are listed in the Annex) (IMTA, SEMARNAT & GIZ, unpublished). Out of these 42 localities, only four have WWTPs functioning at full capacity. Data from 20 of the cities show that 61% of consumed water is collected and treated (IMTA, SEMARNAT & GIZ, unpublished). The gap in wastewater treatment in Mexico can be traced to three main reasons: (1) insufficient installed capacity; (2) installed capacity not operational due to the limited extent of sewerage networks; and (3) inefficient wastewater treatment. Estimates suggest that closing the gap by 2030 will require investments of around USD 8.8 billion (De la Peña,

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[5] Mexico's National Water Commission classifies wastewater as municipal and non-municipal. Municipal wastewater is defined as the effluents generated by urban settlements and collected by urban or rural sewage systems (CONAGUA, 2018b). In 2015, municipal wastewater constituted 52% of all wastewater generated in the country.

[6] The study, commissioned by GIZ and SEMARNAT and undertaken by IMTA in 2018, is not published, but has been shared with the authors of this report.

Figure 17: Water and wastewater data from Mexico compared with the World and Latin America.
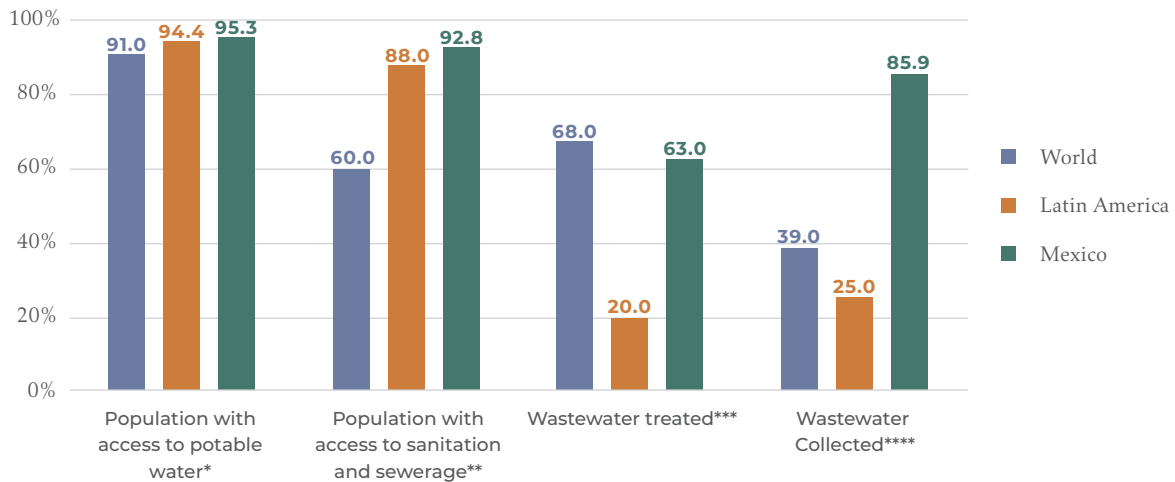
Note: SD Strategies, based on: * (CONAGUA, 2018b), (WWAP, 2017), (CONAGUA, 2018b); ** (WWAP, 2017), (UNICEF and WHO, 2015), (CONAGUA, 2018b); *** (CONAGUA, 2018b); (WWAP, 2017), (CONAGUA, 2018b); **** (UNICEF and WHO, 2017); (WWAP, 2017), (CONAGUA, 2018a).

Ducci and Zamora, 2013). The '2030 Water Agenda', a long-term policy instrument developed in 2010 by the National Water Commission (Comisión Nacional del Agua, CONAGUA) in consultation with multiple stakeholders, includes the goal of treating all municipal wastewater before 2030 (CONAGUA, 2011). For short-term planning, CONAGUA develops a National Water Program every five years. The latest program period, 2014-2018, adopted the target of treating 63% of all wastewater by 2018, compared to a baseline of 47.5% in 2012. The program reached the target in 2017 and, as of 2018, the reported figure was 63.8% (CONAGUA, 2018c).

The next National Water Program (2019 - 2023) is currently under development. The new objectives are yet to be announced but given the importance of sufficient wastewater treatment to achieving Mexico's sustainable development agenda, they are expected to align with the country's long-term international commitments, especially the SDGs. Meeting the SDG target of halving the proportion of untreated wastewater translates into treating at least 80% of total wastewater in the country by 2030. Focusing on large urban settlements, as proposed by the NDC, could streamline the use of financial resources and facilitate the advancement of Mexico's wastewater treatment goals.

The treatment of wastewater is a prerequisite to ensuring public sanitation and people's health (...) and, if neglected, can significantly contribute to increasing carbon emissions.

Figure 18: Water quality in Mexico (CONAGUA, 2018a).
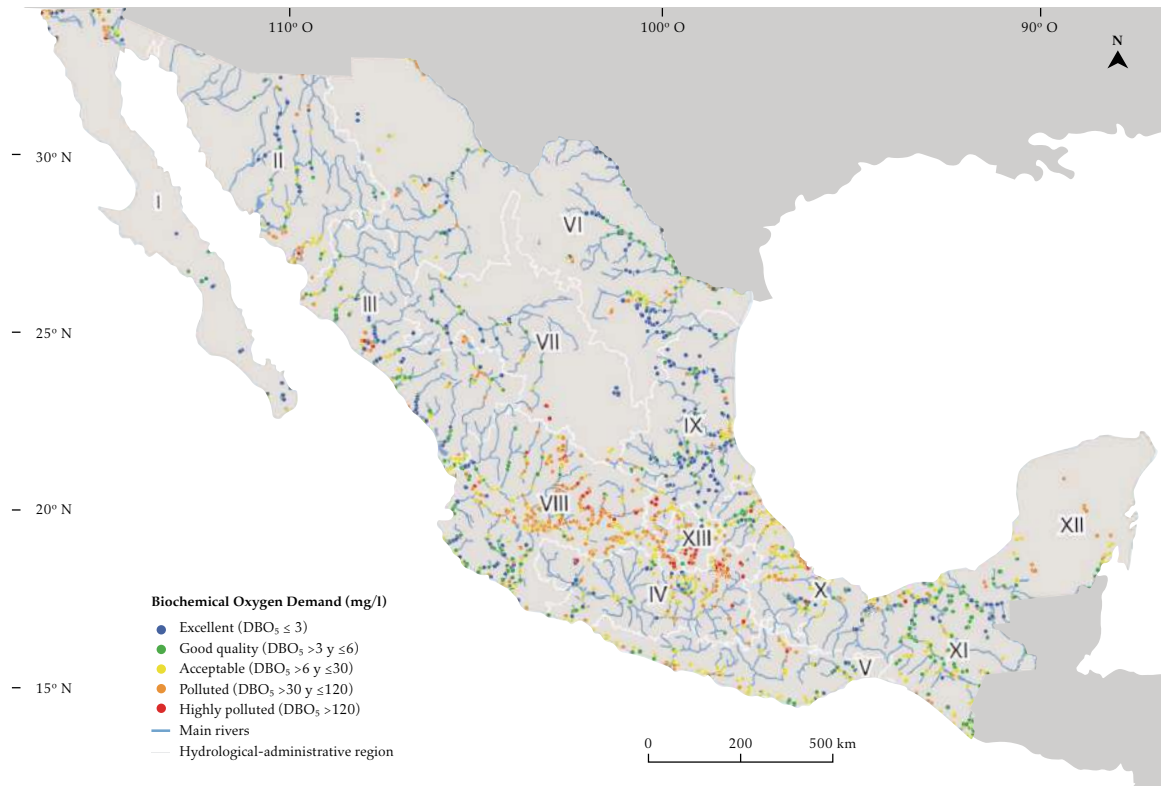
2 TREATING WASTEWATER TO MITIGATE AND ADAPT TO CLIMATE CHANGE

Historically, international climate negotiations have treated adaptation and mitigation measures as different strands of climate action. Yet, in practice, there are clear synergies between them. While wastewater treatment has generally been considered as an adaptation measure in the NDC process, actions in this area can also significantly contribute to mitigation goals.

Wastewater management is a critical component in climate change adaptation. Predictions warn that changing climatic conditions will exacerbate the pressure human settlements place on water systems. Stress factors such as increasing demand and highly variable supplies, in combination with climate change, have the potential to significantly affect water quality (IWA, 2009). In Mexico, annual precipitation across the country is predicted to decrease by 10-20% as a

consequence of climate change (Gobierno de la República de los Estados Unidos Mexicanos, 2016). Mexico's NDC includes commitments to implement adaptation contributions in three areas: adaptation in the social sector, ecosystem-based adaptation (EbA), and adaptation of strategic infrastructure and productive systems. The latter includes the measure of guaranteeing and monitoring the treatment of urban and industrial wastewater in human settlements larger than 500,000 inhabitants, selected as the focus of analysis in this study. Other measures in this action area include:

- Installing early warning and risk management systems;
- Ensuring the safety of strategic infrastructure;
- Incorporating climate change criteria in agricultural and livestock programs;
- Applying environmental protection standards and specifications for adaptation in coastal touristic and real-estate developments;

• Incorporating adaptation criteria in public investment projects that include infrastructure construction and maintenance.

While Mexico's NDC approaches wastewater treatment as an adaptation measure, it is important to consider how its implementation can mitigate climate change impacts in Mexico. The discharge of untreated wastewater contributes significantly to GHG emissions in the form of nitrous oxide and methane and is hence considered an important component in mitigation. It is important to acknowledge that wastewater treatment also emits CO_2 and other GHGs, through the biological processes of treatment plants and the energy used to operate them. However, emissions from untreated sewage water are three times the level of conventional wastewater treatment (IWA, 2009).

In Mexico, treatment and discharge of wastewater are responsible for 22.3 $MtCO_2$-e emissions, corresponding to approximately 3.3% of Mexico's total emissions (SEMARNAT & INECC, 2018). The national Special Program on Climate Change 2014-2018 (Programa Especial de Cambio Climático, PECC) established the target of reducing 2.88 $MtCO_2$-e during its five-year period, through three types of measures including increasing operational efficiency in existing plants, prioritizing infrastructure which includes production and capture of biogas to cogenerate electricity and the use of alternative sources of electricity, and favoring technologies with low energy consumption (CONAGUA, 2011).

Considering the above-mentioned factors, achieving the country's NDC target of "guaranteeing urban and industrial waste water treatment in human settlements larger than 500,000 inhabitants" (Gobierno de la República de los Estados Unidos Mexicanos, 2016, p. 13) should be a high priority in Mexico's climate and development agendas.

3 WASTEWATER TREATMENT AS A DRIVER OF MEXICO'S DEVELOPMENT

Water is the principal medium through which climate change influences ecosystems (UN Water, 2010, p. 1). It is hence intrinsically interlinked with people's livelihoods and well-being (UN-Water, 2010). For instance, "the discharge of untreated wastewater can severely impact human and environmental health, including outbreaks of food, water, and vector borne diseases, induce pollution as well as loss of biodiversity and ecosystem services" (WWAP, 2017, p. 7).

Wastewater treatment is a core element of a country's infrastructure and is thus directly addressed in the SDGs. For example, SDG 6 on Clean water and sanitation seeks to ensure the availability and sustainable management of water and sanitation for all (United Nations, 2019, p. 7). Target 6.1 calls for improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally (United Nations, 2019, p. 7). As seen in Figure 19, linkages can be drawn between the NDC measure on wastewater treatment and the specified social, environmental and economic co-benefits.

In Mexico, treatment and discharge of wastewater are responsible for 22.3 $MtCO_2$-e emissions.

Figure 19: Full range of co-benefits induced by the wastewater treatment NDC measure (own elaboration, based on analysis from Office of the Presidency et al., 2018). The selection of CBs to be quantified is highlighted.
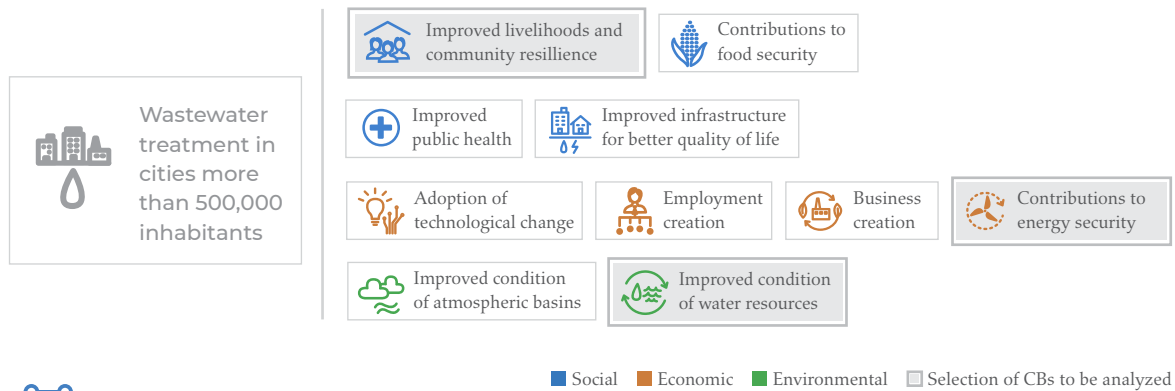
3.1 Social co-benefits

Reusing adequately treated water for suitable uses, such as agriculture, enhances opportunities for food security and can help alleviate stressors associated with increasing water demand (WWAP, 2017, p. 4). Treating wastewater avoids the potential use of contaminated water, "which could result in positive impacts on the natural water balance, soil fertility and human health" (GIZ, 2014, p. 35). It is established that increased wastewater treatment decreases the incidence of diarrheal and parasitic diseases (UNICEF & WHO, 2009). However, it is challenging to measure wastewater treatment's contribution to reducing morbidity and mortality, because of the difficulty of isolating the influence of additional factors, such as sanitation infrastructure coverage, personal hygiene, water quality for food production, drinking-water potability as well as airborne and foodborne transmission (Prüss, Kay, Fewtrell, & Bartram, 2002, p. 537).

3.2 Economic co-benefits

Wastewater can play a central role in a circular economy – a connection that has often been overlooked. The benefits of wastewater treatment are "less obvious and more difficult to assess in monetary terms" (OECD, 2011, p. 16) and thus have often been undervalued. However, there has been a growing recognition of the importance of waste-

water as a "[…] potentially affordable and sustainable source of water, energy, nutrients, organic matter and other useful by-products" (WWAP, 2017, p. 17), the use of which can contribute towards more circular consumption patterns.

In addition to wastewater treatment's potential in the framework of a circular economy, the link between water and employment is well established. Jobs are created throughout the water sector to support safe management of water resources. From the extraction of water to its return to ecosystems, water is a key factor in employment creation (WWAP, 2016).

3.3 Environmental co-benefits

The environmental co-benefits of wastewater treatment are linked to improving water quality through the removal of polluting substances. It generates withdrawal benefits, for example to municipal water supply, irrigated agriculture, and industrial processes. Wastewater treatment also produces in-stream benefits from the water left "in the stream", such as swimming, boating, and fishing (OECD, 2011, p. 17). Additionally, increased wastewater treatment improves the condition of atmospheric basins, due to reduced emissions from effective wastewater treatment. Diverting wastewater from solid body discharge also improves the condition of the soil.

4 ANALYSIS OF SELECTED CO-BENEFITS OF WASTEWATER TREATMENT

The analysis in this chapter utilizes data from the National Housing Commission's (Comisión Nacional de Vivienda) database and includes 54 localities projected to have over 500,000 inhabitants by 2030. The baseline year for the quantification is 2017. Data from additional years are referred to in the discussion, depending on availability.

4.1 Applied scenarios and selected co-benefits

The following three scenarios are used in the analysis of the selected co-benefits:
• Business as usual (BAU)
• Nationally determined contribution (NDC)
• SD+ (2030 Water Agenda scenario)

BAU
This scenario assumes that the wastewater treatment capacity in Mexico remains constant, with no additional treatment capacity developed until 2030. It is based on the "no action scenario" used in a study by IMTA, SEMARNAT & GIZ (unpublished) in which no additional wastewater treatment facilities are constructed and extreme weather events threaten existing wastewater collection infrastructure. This scenario is unlikely, but useful for comparison purposes.

NDC scenario
The NDC target of ensuring water treatment in urban settlements[7] of more than 500,000 inhabi-

tants by 2030 includes the following wastewater treatment components, following the recommendations of the IMTA team (IMTA, SEMARNAT & GIZ, unpublished) as follows:
• Collect 90% of all municipal wastewater generated
• Treat 100% of municipal wastewater collected
• Re-use 80% of municipal wastewater treated

The scenario assumes that the expansion of infrastructure for water collection in localities with more than 500,000 inhabitants is sufficient to collect at least 90% of wastewater generated in 2030 and that municipal wastewater treatment capacity is increasing at a sufficient rate to treat 100% of collected wastewater (by 2030). It is assumed that wastewater treatment capacity is increased to reach 100% treatment of water collected in cities with more than 500,000 inhabitants, but wastewater treatment capacity is not increased outside those localities. It is further assumed that 80% of the treated wastewater is re-used.

SD+ (2030 Water Agenda scenario)
The scenario assumes that Mexico reaches the target stated in the 2030 Water Agenda, increasing municipal wastewater management capacity at a mean annual rate sufficient to collect 99% of all wastewater generated in the country and treat 100% of the collected municipal wastewater (regardless of settlement size) by 2030. Further, it is assumed that 80% of the treated wastewater is re-used.

[7] The term urban settlement is considered equivalent to political divisions called "localities" by Mexican government statistics.

Table 4: Summary of scenario parameters for wastewater treatment.

Scenario	Wastewater collected (%)	Wastewater collected and treated (%)	Treated wastewater reused directly (%)
BAU (no action)	72	63	29
NCD* **Localities > 500,00****	90	100	80
SD+ * **entire country**	99	100	80

Note: * Assumptions. ** The NDC scenario assumes the capacity stays at baseline levels in localities with less than 500,000 inhabitants (CONAGUA, 2018)

The benefits of wastewater treatment are widely acknowledged. However, the full magnitude is rarely considered. Several reasons contribute to this apparent neglection, including the challenge to quantify non-economic benefits and the fact that benefits are highly location-specific and as such difficult to aggregate (OECD, 2011). Based on existing methodologies and available data for quantitative analysis of wastewater treatment, the chapter focuses on three selected co-benefits: improving livelihoods and community resilience, improving the condition of water resources, and contributing to energy security.

4.2 Improving livelihoods and community resilience through wastewater treatment

It is important to analyze the potential of wastewater treatment for improving livelihoods such that the full impact of the NDC measure can be ascertained. Reusing treated water for suitable uses, such as agriculture, can increase food security and help alleviate stressors induced by increasing water demand. Overall, increasing wastewater treatment is expected to have positive effects on freshwater supplies, human and environmental health, livelihoods and poverty alleviation (WWAP, 2017, p. 21).

4.2.1 Methodology
The indicator used to measure wastewater treatment's contribution to improving livelihoods and community resilience in this study is the amount of properly treated wastewater available for suitable reuse. Estimates of the annual amount of wastewater collected, treated and generated are based on parameters described in the study by the IMTA (IMTA, SEMARNAT & GIZ, unpublished) and regards the amount of wastewater generated (187.5 liters per person per day), the goal of collecting 90% of all municipal wastewater, treating 100% of wastewater and reusing 80% of treated wastewater by 2030.

4.2.2 Results
Table 5 presents the results of the municipal waste-

water generated, treated and reused for the baseline year followed by the change in each of the three scenarios. Detailed assumptions as well as methodology for all calculations are presented in the Annex.

The results presented in the table illustrate that under certain assumptions, supporting municipal wastewater treatment and promoting its reuse in line with the NDC target would make 4.6 billion cubic meters of appropriately treated water available for utilization in suitable activities, such as agriculture and sanitation. It would help minimize withdrawals of fresh water for such purposes. The use of treated wastewater would thus decrease the vulnerability of communities and their economic activities to water scarcity and droughts. The volumes of potential water for reuse are significant in the context of water consumption in Mexico. The amount of water distributed in the existing 86 irrigation districts in Mexico during the 2015-2016 agricultural year was approximately 29 billion cubic meters (CONAGUA, 2018a). Consequently, the treated wastewater available for reuse due to successful achievement of the NDC measure could contribute approximately one sixth (4.59 billion cubic meters) of the water that was used in Mexico's irrigation districts in one agricultural year. The more ambitious SD+ scenario would result in a much larger volume of water for reuse: 7.45 billion cubic meters, amounting to one quarter of the water used in Mexico's irrigation districts in one agricultural year.

4.2.3 Discussion
The NDC scenario results in the treatment of 61% of all wastewater generated countrywide. Without increasing wastewater treatment in the rest of the country, this would not be sufficient to reach the SDG 6 Clean water and sanitation target 6.3 of halving the percentage of untreated municipal wastewater in the country. The SDG target is equivalent to treating 81% of collected municipal wastewater countrywide by 2030. In order to meet that target, wastewater treatment capacity would need to be increased to reach at least 66% coverage of municipal wastewater treatment in localities with less than 500,000 inhabitants.

Table 5: Wastewater generated, collected and treated at national level in Mexico, for the analyzed scenarios. (1) (CONAGUA, 2018) and (2) (CONAVI, n.d.).

	Baseline 2017*	2030 under each scenario		
		BAU [no action]	NDC	SD+ [2030 Water agenda]
Population (millions) · Country (1)	122.275	137.483	137.483	137.483
Municipal wastewater generated (billion cubic meters)	7.41 (2)	9.41	9.41	9.41
Wastewater collected · Volume (billion cubic meters) · Proportion from wastewater generated	6.79 (2) 92%	6.79* 72%	7.05 75%	9.31 99%*
Wastewater collected and treated · Volume (billion cubic meters) · Proportion from wastewater collected · Proportion from wastewater generated	4.28 (2) 63% 58%	4.28* 63% 45%	5.74 80% 61%	9.31 100%* 99%
Wastewater untreated · Volume (billion cubic meters) · Proportion from wastewater generated	3.13 42%	5.13 55%	3.67 39%	0.09 1%
Wastewater reused · Volume (billion cubic meters) · Proportion from wastewater treated · Proportion from wastewater generated	1.25* 29% 17%	1.25* 29% 13%	4.59 80%* 49%	7.45 80%* 79%

Note: * Assumptions. (1)

In addition to contributing to SDG 6 (Clean water and sanitation), reducing the proportion of untreated wastewater and reusing properly treated wastewater treatment for agricultural purposes would contribute to the advancement of SDG 2 (Zero hunger). Specifically, it can positively contribute to target 2.3 which seeks to "double the agricultural productivity and incomes of small-scale food producers [...]" (United Nations, 2019, p. 2) and target 2.1 to "end hunger and ensure access by all people [...] to safe, nutritious and sufficient food all year round" (United Nations, 2019, p. 2).

Also, the reuse of wastewater for non-potable uses in drought-prone localities can contribute to SDG 11 Sustainable cities and communities, particularly to target 11.5 which aims to "significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations" (United Nations, 2019, p. 12).

4.3 Wastewater treatment's contribution to improving water resources

Removing pollutants from wastewater that is discharged into water bodies will not only improve the quality of hydrological resources, but also the health of critical ecosystems, as well as the sustainability of human use of clean water. According to the United Nations World Water Report, "organic pollution (measured in terms of five-day biochemical oxygen demand – (BOD_5)) can have significant impacts on inland fisheries, food security and livelihoods, severely affecting poor rural communities that rely on freshwater fisheries" (WWAP, 2017, pp. 13-14).

4.3.1 Methodology
This calculation uses the volume of organic load removed from wastewater to measure wastewater treatment's contribution to improving the condition of water resources. This is calculated using the BOD_5 indicator. The factor used for the five-day average concentration of BOD_5 is 270 grams/liter. The value is consistent with the range of BOD_5 for average and high concentrations for typical composition of domestic wastewater, according to the Mexican Manual for Water, Drainage and Sanitation (SEMARNAT, 2016). It is assumed in the calculation that reused water must meet national standards to be suitable for "[…] services to the public with indirect or occasional contact" (NOM-001-SEMARNAT, 1996) and that the water which is not reused has to meet the standard for "protection of aquatic life" (NOM-003-SEMARNAT, 1997)[8] (CONAGUA, 2013). It is further assumed that the volume of organic pollutants removed in the treatment process remains constant until 2030. The estimation builds on the volume of municipal wastewater generated and treated, calculated in the previous section (see Table 5).

4.3.2 Results
Table 6 displays the volume of organic load removed to prevent discharge into water bodies. Detailed assumptions and methodology for calculations are presented in the Annex.

The table illustrates that under a set of assumptions, increasing wastewater treatment capacity to meet the NDC target would avoid discharge of 1.34 million tons of organic pollutants into Mexican water bodies and soil by 2030. This is equivalent to avoiding the organic pollution contained in wastewater discharges of approximately 20 million Mexican households in one year. It would have a positive

[8] NOM-001-SEMARNAT 1996 is the Mexican standard for maximum allowed contaminant limits for wastewater discharged into national water bodies or properties. NOM-003-SEMARNAT 1993 is the Mexican standard for maximum limits allowed of contaminants of treated wastewater reused in public services.

Table 6: Amount of organic load not discharged in water bodies, own calculations based on Mexico Water Atlas 2018 (CONAGUA, 2018).

Parameter	Baseline 2017	Scenario		
		BAU [no action]	NDC	SD+ [2030 Water agenda]
Amount of organic load -BOD_5- generated (million tons)	2.00	2.54	2.54	2.54
Organic load -BOD_5- removed (million tons)	0.92	0.92*	1.34	2.18
Organic load -BOD_5- not removed · Amount (million tons) · Difference with respect to baseline (million tons)	1.08 -	1.62 0.54	1.20 0.12	0.36 -0.72

Note: * Assumptions.
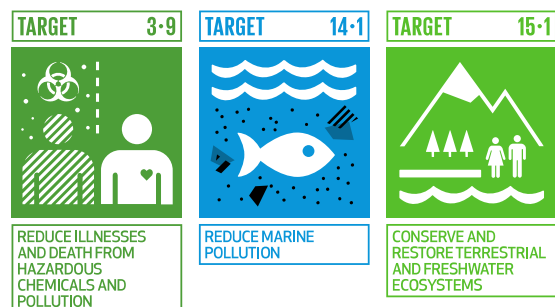
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effect on the quality of water and soil, which in turn generates benefits for human health, ecosystems as well as productive and recreational activities depending on clean water availability and access. Achievement of the SD+ Water agenda scenario would nearly double the benefits, avoiding the discharge of 2.18 million tons of organic pollutants, equivalent to the organic pollution through wastewater generated by 33 million Mexican households in one year. On the other end of the scale, failing to increase wastewater treatment capacity would result in 1.62 million tons of pollutant being dumped into rivers, creeks, oceans and other bodies of water in 2030 – an increase of 540,000 tons compared to 2017. This would lead to negative effects on human health, quality of water and soil, aquatic life, ecosystems and other aspects discussed above.

4.3.3 Discussion
Although estimating wastewater treatment's impact on morbidity and mortality rates presents methodological challenges, it must be recognized that preventing organic and other pollutants to enter water bodies and soils will contribute to achieving SDG 3 Good health and well-being target 3.9 which aims to substantially reduce "[…] the number of

deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" (United Nations, 2019, p. 4). Additionally, by preventing pollutants from reaching the oceans, wastewater treatment helps advance SDG 14 Life below water. It specifically contributes to target 14.1 to "prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" (United Nations, 2019, p. 15). Increasing wastewater treatment further contributes to the health of inland ecosystems, thus supporting SDG 15 Life on land target 15.1 to "ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services […]" (United Nations, 2019, p. 16).

TARGET 3·9	TARGET 14·1	TARGET 15·1
REDUCE ILLNESSES AND DEATH FROM HAZARDOUS CHEMICALS AND POLLUTION	REDUCE MARINE POLLUTION	CONSERVE AND RESTORE TERRESTRIAL AND FRESHWATER ECOSYSTEMS

4.4 Improving energy security through wastewater treatment

The organic matter contained in wastewater from sewage systems can become a valuable resource in sludge-to-energy systems (WRI, 2017). For instance, biogas generated from organic matter can be used to meet local energy needs, processed further to be used as a substitute of natural gas or transformed into electricity.

4.4.1 Methodology
In this section, the contribution of wastewater treatment to energy security is estimated by the amount of biogas which can be obtained from the wastewater treatment process and used to produce energy, either in the form of heat or electricity. The discussion of potential biogas production from organic matter in wastewater is based on the results of existing studies developed by academic and technical cooperation organizations, among them the GIZ Program Converting Solid Urban Waste into

Energy (Aprovechamiento Energético de Residuos Urbanos- EnRes). No scenarios are applied in the quantification of this co-benefit, due to methodological complexities in linking biogas potential directly to the volume of wastewater.

Although currently biogas produced from by-products of wastewater treatment is generally not utilized in Mexico, a 2018 publication of the GIZ-EnRes Program identifies 11 treatment plants with existing facilities able to produce biogas in the country, nine of which are currently in operation (GIZ, SEMARNAT & SENER, 2018). These projects are summarized in the Annex.

4.4.2 Results
Many more WWTPs could be upgraded to produce biogas beyond the existing ones already equipped with adequate facilities to do so. Even the most conservative estimates suggest that the number of WWTPs that could also be producing biogas is more than twice the number of plants currently equipped. The study identifies 27 WWTPs with potential to

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Utilizing the energy potential of wastewater treatment can positively impact both resource efficiency and operation costs of the wastewater treatment plants, while making a contribution to climate change mitigation.

produce electricity from biogas (GIZ, SENER, SEMARNAT, CONAGUA, & ANEAS, 2017).

Based on a conservative estimate, the 27 plants identified by the EnRes Program have the potential to produce 146.5 million cubic meters of biogas and generate 304 GWh of electricity per year. In relation to the NDC measure, it is important to consider that 16 of these plants are in localities with more than 500,000 inhabitants, and together they can potentially produce 48 million cubic meters of biogas and generate 100 GWh of electricity annually. This is equivalent to powering approximately 50,000 Mexican households for one year (Shinkthatfootprint. com, 2014). The more ambitious SD+ scenario would see the capacity of the 27 plants fully utilized, thus delivering an even greater benefit.

4.4.3 Discussion

Utilizing the energy potential of wastewater treatment can positively impact both resource efficiency and operation costs of the wastewater treatment plants, while making a contribution to climate change mitigation. Producing at least 146.5 million cubic meters of biogas can support the heat and electricity needs of WWTPs operations.

Realizing the potential clean energy contribution of wastewater-based biogas and thus reducing the use of conventional energy sources would contribute to the reduction of GHG emissions. As such, it would allow for capitalizing on the synergies between climate change adaptation and mitigation sought by the Mexican government. It would also support the achievement of SDG 7 Clean and affordable energy for all target 7.1 which seeks to "ensure universal access to affordable, reliable and modern energy services" (United Nations, 2019, p. 8).

TARGET 7·1

UNIVERSAL ACCESS TO MODERN ENERGY

The benefits of utilizing by-products of wastewater treatment for energy efficiency presented should be considered when developing plans to implement the NDC. The construction of new wastewater treatment facilities for upscaling overall wastewater treatment capacity in the country should take this into account by including technologies that will allow the utilization of the biogas potential.

5 SUMMARY AND OUTLOOK

This chapter illustrates that increasing wastewater treatment to reach Mexico's NDC goal would result in significant contributions to the implementation of SDGs in the country. Beyond direct contributions to SDG 6 Clean water and sanitation, increasing wastewater treatment would also support broader SDGs by:

- Producing 4.6 billion cubic meters of water for reuse in agricultural and urban non-potable needs, thereby contributing to the achievement of SDG 2 (Zero hunger) and SDG 11 (Sustainable cities and communities).

- Avoiding 1.34 million tons of organic pollutants being dumped into bodies of water such as rivers, lakes, ravines and the ocean, which helps the country achieve SDG 3 (Good health and wellbeing), SDG 14 (Life below water) as well as SDG 15 (Life on land).

- Producing at least 146.5 million cubic meters of biogas can support the heat and electricity needs of WWTPs operations and reduce GHG emissions, therefore contributing to SDG 7 (Clean and affordable energy). The amount could be much larger if developments of new treatment capacity would incorporate suitable technologies for biogas production.

The scenario analysis further provides some interesting conclusions regarding the probability of meeting the SDG target 6.3 of halving the proportion of untreated wastewater by 2030:

- Failing to improve wastewater treatment capacity under the BAU scenario would be a challenging setback, since wastewater generation increases with the growing population. Thus, without targeted action, less than half (45%) of the wastewater generated would be properly collected and treated in 2030. This would represent a significant step back from the baseline level of 58% of wastewater collected and treated in 2017.

- Concentrating efforts on reaching the NDC target of achieving 100% wastewater treatment in localities with more than 500,000 inhabitants would result in the treatment of 61% of all wastewater generated countrywide. Without increasing wastewater treatment in the rest of the country, this would not be sufficient to reach the SDG 6 target 6.3 of halving the percentage of untreated municipal wastewater in the country[9]. The SDG target is equivalent to treating 81% of collected municipal wastewater countrywide by 2030. To meet the NDC measure while achieving the SDG 6 target, wastewater treatment capacity should be increased to reach at least 66% of collected wastewater treatment in all localities with less than 500,000 inhabitants. Alternatively, the implementation of the SD+ scenario would be effective in meeting the SDG target.

- Focusing efforts on medium to large settlements is likely the most cost-effective way to address exposure of the large parts of the population to poor quality water in their area of residence. Trying to cover localities of all sizes across the country is a more complex task. However, concentrating on the largest population centers could contribute to widening inequalities between the larger and smaller municipalities. Both of these aspects should therefore be taken into account when planning further development of the wastewater treatment capacities in the country.

Mexico has an opportunity to increase climate ambition in wastewater treatment and maximize the induced co-benefits from it. These co-benefits

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[9] SDG Target 6.3 calls for halving the percentage of untreated wastewater. Since the percentage of wastewater treated in 2016 was 58%, meeting the target requires reducing untreated wastewater by 21 percentage points, which is equivalent to reaching 81% coverage.

include improving livelihoods and community resilience, improving the condition of water resources and increasing energy security through bioenergy production, among others. The long-term policy instrument, the 2030 Water Agenda, aims at 100% wastewater treatment coverage by 2030 and could serve as a fitting target for adoption in the next NDC review.

Figure 20: Summary of co-benefit results and links to SDGs stemming from wastewater treatment NDC measure.

4
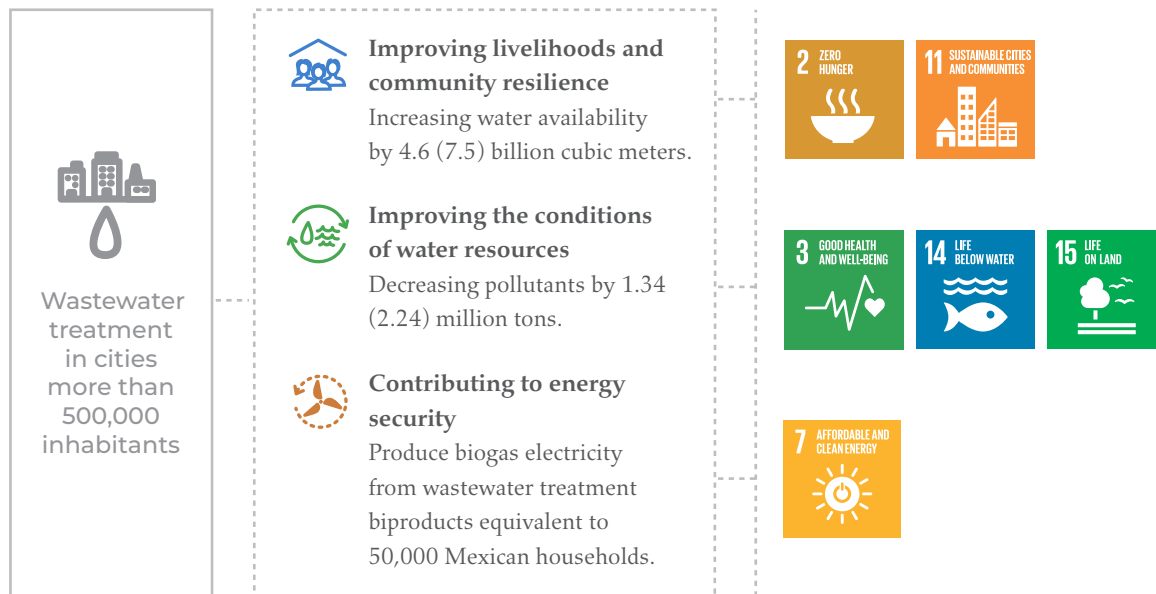
BOOSTING ELECTRIC VEHICLES TO ADVANCE THE WELL-BEING OF MEXICANS

KEY FINDINGS

- Electric vehicles could be the subject of a new climate commitment in the transport sector. Mexico has already set a domestic target of 500,000 electric vehicle sales by 2030.
- Electric vehicles (EVs) can reduce local air pollution and related diseases and deaths in urban areas, an enormous ongoing problem in Mexico. To maximize this potential, a distinct shift towards renewably produced electricity must occur.
- EVs are not a panacea for all deficiencies of Mexico's transport system and only have limited impact. Significant attention should also be directed to improving the capacity and quality of Mexico's public transportation, as well as freight, rail and aviation transport. Incentives for modal shifts from private vehicles to public transport and electrifying public transportation could radically reduce urban PM emissions and the health impacts associated with them.

- Increasing the sales of EVs to 500,000 in 2030 could reduce annual gasoline demand of motor vehicles by 1%, significantly increasing energy security and advancing **SDG 7** (Clean and Affordable Energy). As much as 5% of gasoline would be saved in the SD+ scenario which anticipates just under 3.7 million EVs sold.
- EV production and its associated infrastructure pose an opportunity to generate additional jobs in Mexico, contributing to **SDG 8** (Decent Work and Economic Growth). Implementation could create:
  » At least 2,000 jobs in Mexico in the NDC-compatible scenario.
  » Over 14,000 jobs, in the more ambitious SD+ scenario.
  » This would be despite a globally declining automotive industry workforce as the result of a transition away from cars powered by combustion engines, which are more labour-intense than EVs.

Motor vehicles today are a primary mode of transportation in Mexico. With the rapid growth of cars, not only are inhabitants of Mexico's largest cities suffering from sharp increases in air pollution, the future development of transport in Mexico will also determine the pathways of carbon emissions of the country.

The transition from internal combustion engine vehicles (ICEVs) to EVs opens the door to an array of potential social, environmental and economic co-benefits. EVs can improve local air quality and public health, as well as stimulating employment, business creation, new infrastructure and innovation. This chapter presents a discussion and analysis of the development benefits and positive side effects that an integration of EVs into the Mexican transportation system can have on society, economy, the atmosphere and public health, and the country's energy security. Mexico has established itself as a leader on electro-mobility in the Latin American and Caribbean region: The country boasts the largest charging infrastructure and one of the most extensive battery electric vehicle and plug-in hybrid vehicle (PHEV) fleets. Mexico's prominent automotive industry has an established, global track record, which could be leveraged in order to become a regional hub in the production of EVs and contribute to the achievement of the country's climate goals.

The selected measure, serving as the basis for this chapter, is the target of 500,000 EV sales in Mexico by 2030. The target used in this chapter is adopted from the Mexican National Electromobility Strategy (SEMARNAT, 2018) and contributes to Mexico's GHG mitigation efforts in the transport sector. There are no specific EV measures included in Mexico's NDC commitment, thus electrification of the road transport sector provides an opportunity for increasing ambition in Mexico's NDC review.

Note that this measure was selected not because it is the area with the greatest GHG emissions reduction potential in Mexico but because of its prominence in the international discourse on the future of the private transport sector.

1 BACKGROUND: EVs AND TRANSPORT IN MEXICO

Motor vehicles are a primary mode of transportation in Mexico. In 2017, there were approximately 45.5 million registered vehicles in circulation (INEGI, 2019) and more than 1.5 million new light vehicles sold (AMIA, 2018). It is estimated that there will be approximately 69 million vehicles on Mexican roads by 2030, based on the growth rate observed between 2006 and 2017 of 3.3%. The rapid growth of the number of cars in Mexico has led to sharp increases in air pollution and smog in Mexico's largest cities. This has been an ongoing struggle particularly in Mexico City (Ciudad de México, CDMX), which prompted non-circulation laws for vehicles in the late 1980's. These laws prohibit vehicles from being on the road on certain days of the week and are still in effect at present.

Complementary to the growing number of vehicles on Mexican roads, the number and share of EVs in Mexico is growing: Between the beginning of 2016 and June 2018, 590 BEVs, 2,419 PHEVs and 23,892 conventional hybrids were registered (UN Environment, 2018). Of the total vehicle sales in 2017, hybrid vehicles constituted 0.68% (10,512 vehicles) and BEVs represented 0.02% (257 vehicles) (Mexico Business Publications S.A., 2018).

1.1 Charging infrastructure

Mexican charging infrastructure stands out region-

ally. As of 2018, Mexico had a total of 1,528 public charging stations (SEMARNAT, 2018) over 1,000 more than any other country in Latin America. Public and private actors have actively financed and developed charging facilities in Mexico. Through the Energy Transition Fund, SENER, Petróleos Mexicanos (PEMEX) and the Federal Electricity Commission (Comisión Federal de Electricidad [CFE]) are carrying out a program to deploy public, cost-free charging stations compatible with all EVs in the market. In cooperation with the automotive industry and the government of Mexico City, CFE will construct the first network of charging stations connecting cities across 10 states (CFE, 2017; SEMARNAT, 2018), which will be the largest corridor in the region (UN Environment, 2018). In 2015, a public-private partnership between CFE, BMW, Walmart and Schneider Electric placed the first four charging stations along CDMX's metropolitan area in Walmart stores, all powered by wind generation (El Economista, 2015; Forbes Mexico, 2015; Walmart Mexico, 2015)

1.2 Policy landscape

The National Electro-Mobility Strategy 2030 (SEMARNAT, 2018) is the primary document addressing the transition to electric mobility in Mexico. By fostering the development of electric mobility, it aims to increase national ambition in reducing GHG emissions of the transport sector (SEMARNAT, 2018). The strategy seeks to achieve multiple objectives: reduce urban pollution from ICEVs, achieve Mexico's NDCs, leverage existing mobility systems to boost the use of renewable energy, promote smart mobility, and develop industries for Mexico to become the regional center for EV production. The specific electro-mobility

targets are for EVs to represent 5% of new vehicle sales by 2030, 50% by 2040, and 100% by 2050, including both light and heavy-duty vehicles (SEMARNAT, 2018).

The mechanisms that comprise the federal incentives system for electro-mobility are the exemption of the Tax on New Automobiles (ISAN), increased deductions from the Income Tax (ISR) for both EVs and HEV (as well as hydrogen engines), and fiscal credits to invest in the placement of public charging stations. Additionally, CFE provides independent household meters to differentiate household electricity consumption from electricity for EV charging, which is priced at a lower tariff. Some states provide exemptions for EVs from the yearly Tax on Vehicle Possession and Use (ISTUV), biannual car emissions verification mandates, and from vehicle circulation restrictions (SEMARNAT, 2018). The strategy will seek to implement incentives and maximize their impact (SEMARNAT, 2018).

1.3 Automotive industry

The transport sector is a key pillar of the Mexican economy: exports from the sector made up USD 100 billion in 2016, 25% of Mexico's total exports that year. Mexico is the 6th largest light vehicle producer (3.9 million vehicles in 2018) (AMIA, 2018) and 3rd largest exporter of light vehicles globally (Mexico Business Publications S.A., 2018). There are more than 875,000 people employed in Mexico's auto industry (Franco & Morán, 2016): 793,456 people were employed in the auto parts subsector and 81,927 in the auto manufacturing subsector in 2015. The EV target provides the potential for Mexico to position itself as a leader in EV production and manufacturing.

2 EVs FOR EMISSIONS MITIGATION

The transport sector – incorporating road, rail, air and marine transport – accounts for 25% of global GHG emissions (International Energy Agency [IEA], 2019). Road transport accounts for 74% of these emissions. Transport sector emissions are forecast to have the highest growth in emissions to 2030, with an estimated increase of 20% between 2015 and 2030 (UNFCCC, 2015). Diesel transport in particular is one of the world's major sources of black carbon, an SLCP which is the second highest contributor to global warming after carbon dioxide (CO_2) (World Health Organization [WHO], 2019). The transport sector is the largest source of emissions in Mexico and mirrors the global share, constituting 25.1% of the country's total carbon dioxide equivalent (CO_2-e) emissions. 93% of these emissions (23.4% in total) come from road transportation (SEMARNAT & INECC, 2018). This positions the transport sector as the primary target for immediate attention in order to reduce the country's emissions in line with its NDC commitment. Mexico's General Law on Climate Change recog-

nizes this fact, setting the unconditional target of reducing GHG emissions of the transport sector by 18% by 2030 (Cámara De Diputados Del H. Congreso De La Unión, 2012).

Electro-mobility is related to three measures within Mexico's unconditional pledges: penetration of zero-emission technologies in the vehicle fleet, efficiency norms for light vehicles, and integrated public transport systems and urban planning (SEMARNAT, 2018). The selected measure for this chapter – 500,000 EV sales by 2030 – has a mitigation potential of 765 kilotons (kt) of CO_2-e (when the electricity supplied to the EVs comes from a BAU electricity mix). The mitigation potential of the selected 'NDC-compatible' target is relatively low in comparison to the potential of other transport-related measures in the current NDC. EVs can reduce SLCPs and black carbon, which is a specific focus of Mexico's NDC commitment. Additionally, the shift to EVs underpins the country's ambition to improve the efficiency of light vehicles and further builds the case for transition to a cleaner electricity generation sector (Office of the Presidency et al., 2018).

The transport sector is the largest source of emissions in Mexico and mirrors the global share, constituting 25.1% of the country's total carbon dioxide equivalent emissions. 93% of these emissions come from road transportation.

3 EVs AS A DRIVER OF MEXICO'S DEVELOPMENT

The transition from ICEVs to EVs entails an array of social, environmental and economic co-benefits. In addition to the GHG emissions mitigation, EVs can improve the quality of air and water, enhance public health, and stimulate economic benefits in innovation, employment creation and energy security in Mexico. Furthermore, sustainable trans-portation can be an enabler of development and is thus incorporated in SDG 11 on Sustainable cities and communities, primarily through target 11.2 which seeks to "provide access to safe, affordable, accessible and sustainable transport systems for all […]" (United Nations, 2019, p. 11). The co-benefits linked to the rollout of 500,000 EVs in the Mexican transport sector (Office of the Presidency et al., 2018) are shown in Figure 21.

Figure 21: Full range of co-benefits induced by the EVs prospective NDC measure (SD Strategies, based on analysis from Office of the Presidency et al., 2018). The selection of CBs to be quantified is highlighted.
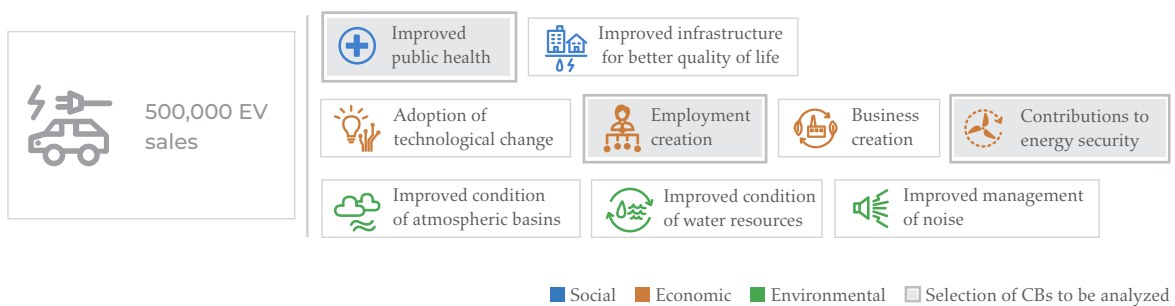
3.1 Social co-benefits

Health risks associated with polluted air are often underestimated and are strongly associated with premature mortality (Heo, Adams, & Gao, 2016a; Metrics, 2017). Exposure to GHG emissions, including tropospheric ozone (O_3), SLCPs and particulate matter (PM) are all associated with increased mortality and illness. ICEVs are responsible for a significant share of urban PM and GHG emissions, polluting the air and the environment where populations are concentrated, and exposure is highest. Air pollution imposes elevated risk of contraction of NCD, which are responsible for 71% of all deaths globally each year (WHO, 2018).

EVs are able to eliminate tailpipe emissions from vehicles, improving local air quality through the reduction of urban air pollution and providing associated health benefits. This can decrease the risk of significant health impacts to exposed populations, such as stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma. These benefits are maximized when EVs are powered by clean electricity.

Access to EVs can improve the infrastructure and mobility within cities by providing access to less polluting means of transportation. This is of particular relevance in the case of Mexico City, due to its non-circulation laws in which ICEVs are forbidden to drive on assigned days of the week. The construction and expansion of charging infrastructure is of critical importance to decrease barriers of EV utilization and to provide a similar charging availability and experience as with conventional vehicles today. EVs can subsequently contribute to improved infrastructure in the country, which, combined with several other co-benefits, can lead to better quality of life.

3.2 Economic co-benefits

The rollout of 500,000 EVs in Mexico by 2030 requires retrofitting existing or constructing new production facilities to meet the alternate assembly requirements of EVs. This also applies to the manufacturers of EV parts and presents the opportunity for new jobs and businesses to provide technical services and the required manufacturing technologies. Retraining the workforce will be necessary to handle the change, inducing further growth in the tertiary sector.

The adaption of the technological change in the drivetrain of vehicles will decrease gasoline usage in the transport sector. The shift from gasoline-fueled ICEVs to electrically-powered vehicles poses the opportunity to reduce Mexico's dependence on imported gasoline for transportation, particularly from U.S. sources. By increasing the penetration of domestic renewable energy generation, domestic energy use and energy security would be further increased in the country.

3.3 Environmental co-benefits

The use of fossil fuels is associated with the emission of a number of gases that affect the earth's atmosphere and can contribute to the acidification of rainfall, subsequently affecting water resources. EVs do not emit tailpipe emissions and thus can improve local air quality. Other ancillary benefits of EVs can include reduced noise pollution and its associated health impacts. A major source of noise of an ICEV at lower speeds is emitted by the drive-train, rather than aerodynamic noise or tire noise. By substituting combustion-based engines with electric engines, the noise emissions of vehicles can be decreased. The dominant driving scenario within a city is characterized by stop-and-go traffic rather than constant traffic flow. Hence, particularly acceleration and motor brake noises could be decreased by EVs, as EV engines emit higher frequencies that are not transmitted as far as the lower frequencies of ICEV engines (Barnard, 2016).

4 ANALYSIs OF SELECTED CO-BENEFITS OF EVS

4.1 Applied scenarios and selected co-benefits

The analysis in this section concentrates on three important co-benefits of EVs, namely creating jobs, improving energy security and improving public

Figure 22: Cumulative EV sales per scenario to achieve targets (2019 to 2030).
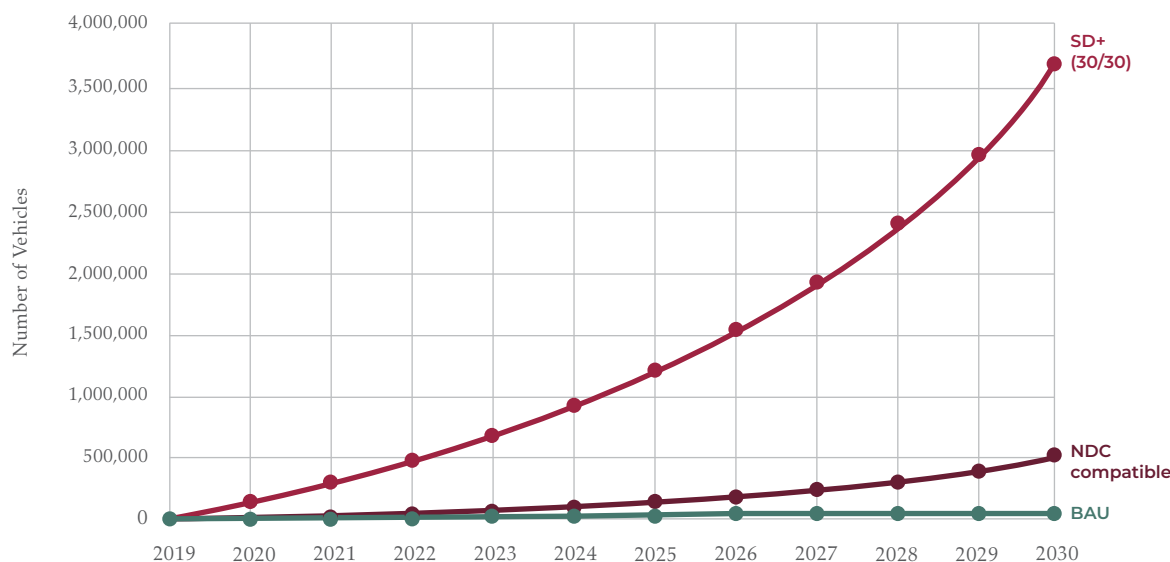
health. Three scenarios are considered in the analysis specified in the table below. All scenarios consider a period under review of twelve years, from 2019 to 2030.

1. Business as usual (BAU)
2. Nationally determined contribution (NDC-compatible)
3. SD+ (30/30)

BAU

This scenario maintains the current share of EVs of total vehicle sales, 0.1%, from 2019 to 2030. This results in 22,326 total EV sales by 2030.

NDC-compatible

This scenario achieves 500,000 EV sales by 2030, adopting a constant growth rate of 0.36% in the EV share of total vehicles sold per year. The NDC-compatible scenario is adopted from SEMARNAT's national electro-mobility strategy.

SD+ (30/30)

This scenario adopts the IEA's EV 30@30 campaign target to achieve 30% EV sales in 2030 (3.67 million EVs by 2030). This scenario uses a constant growth rate in the share of EV sales of 2.7% per year.

4.2 Employment creation from EVs

4.2.1 Methodology

The selected indicator for this analysis is the number of jobs (in person-years) created through the production of EVs to reach the respective targets. The methodology focuses specifically on measuring the direct employment effects of the drivetrain production of EVs[10]. The analysis focuses only on job-creation potential of EVs and does not consider job losses in the ongoing production and manufacturing of ICEVs in Mexico. It is assumed that the vehicles are produced entirely within the country.

The drivetrain production of EVs is split up into different phases of the value chain:

1. Electric motor
2. Battery production (without cells)
3. Power electronics
4. Assembly

The four phases are distinguished from the assembly of ICEVs, as these require different labor inputs. The four phases of the value chain are allocated with different employment factors per unit of produced drivetrain, as shown in Table 7.

Table 7: Employment factors per value chain phase.

Value chain	Employment factors
Electric motor	0.00143
Battery (without cells)	0.00163
Power electronics	0.00054
Assembly	0.00036
Total	0.00395

To determine the total number of jobs created per value chain phase, the number of produced drivetrains is multiplied by the employment factors per unit of the drivetrain.

The total employment of the EV production is derived by adding together the created employment of all four value chain phases. Detailed information of the methodology and underlying assumptions related to these calculations can be found in the Annex.

4.2.2 Results

Figure 23 illustrates the positive employment effects of the drivetrain production of EVs for each scenario. Employment is directly linked to the rollout of vehicles.

Figure 24 shows the total number of jobs (person-years) created in Mexico from the drivetrain production, between 2019 and 2030 for the respective scenarios.

[10] The methodological approach is derived from an extensive bottom-up study by Frauenhofer IAO to quantify employment effects, caused by the electrification of the drivetrain of vehicles (Bauer et al., 2018).

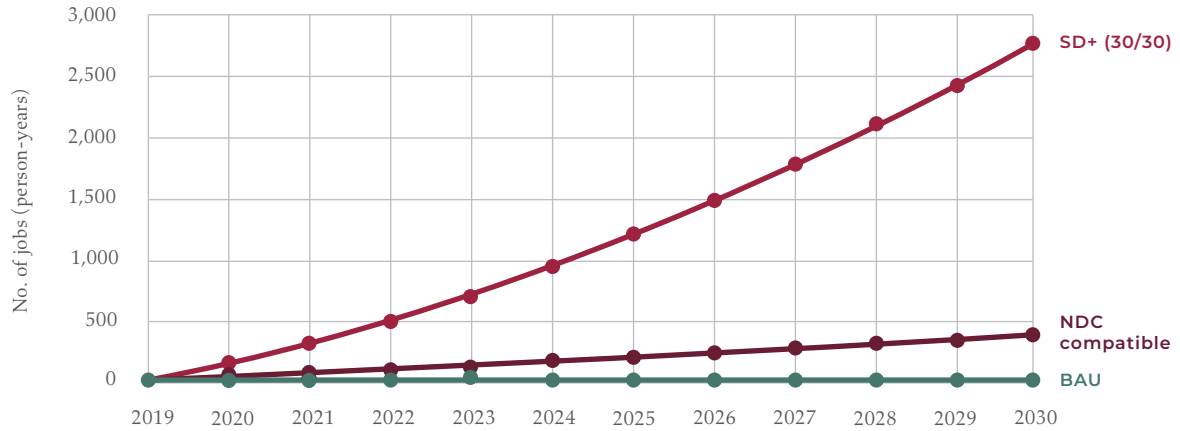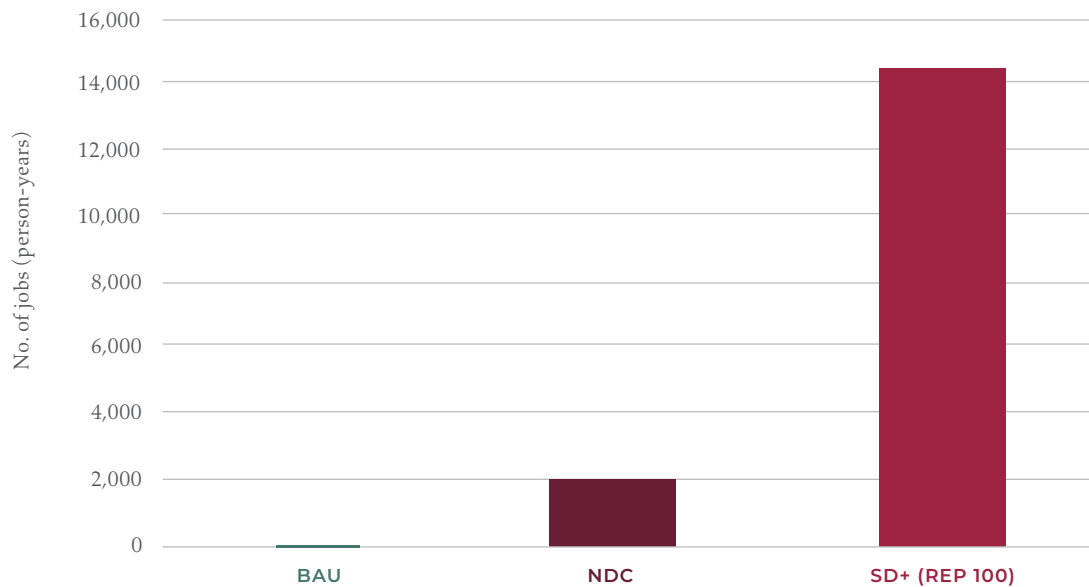**Figure 23:** Jobs created through the EV value chain per year (2019 to 2030).

Figure 24: Total jobs created through the EV value chain (2019 to 2030).

4.2.3 Discussion

In the BAU scenario, a total of 88 jobs-years is created in the period under review. This is due to the constant small share of 0.1% EV sales compared to the total vehicle sales per year. In the NDC-compatible scenario, 1,888 job-years are created relative to BAU, which are representative of 500,000 EV sales by 2030. In the SD+ scenario, 14,422 job-years are created relative to BAU resulting from a total of 3,671,691 EV sales by 2030. The modest level of job creation can contribute towards the achievement of SDG 8 (Decent Work and Economic Growth). In particular, government support for innovation and growth in EV manufacturing can directly contribute to the SDG 8 target 8.3, promoting "development-oriented policies that

support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises […]" (United Nations, 2019, p. 8). Furthermore, employment creation from EVs can serve towards the achievement of SDG 8 target 8.5, to "achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities […]" (United Nations, 2019, p. 8).

TARGET 8·3

PROMOTE POLICIES TO SUPPORT JOB CREATION AND GROWING ENTERPRISES

TARGET 8·5

FULL EMPLOYMENT AND DECENT WORK WITH EQUAL PAY

The obtained results account for direct employment in the considered value chain phases and represent 79% of the total value chain of a Mexican EV's assembly. They include the production of the electric motor, battery (without cells), power electronics and the assembly of the vehicle (Arroyo, Villasana, & Ruíz, 2017). They do not include indirect and additional induced employment resulting from activities related to the rollout of EVs. Indirect employment in early stages includes the expansion of the charging infrastructure at the four primary locations for EV charging: the home, workplace, destination and on-route. Besides construction work and maintenance of the grid and charging points, the technology for fast charging must be developed. In later stages of EV development, an increase in recurring services is expected, such as operator services (maximizing utilization of charging points), driver services (making charging a "one-click experience") and additional services (peak load management, energy storage solutions, data utilization).

Consideration of the indirect and induced jobs from EVs would likely result in significantly larger employment creation impacts than those calculated in this analysis.

Despite the relatively optimistic picture of employment creation that the results portray, there is an ongoing general trend in the automotive industry towards digitization and automation. This is gradually enhancing the machine-based share of added value in the production lines of vehicle assembly and independent of the produced vehicle type (ICEV/EV). This trend is responsible for reducing employment in the sector worldwide.

The automation of vehicle production leads not only to changes in the required workforce, but also in the required skill sets. EVs are not as complex as ICEVs to produce and amplify the negative employment effects driven by digitization. This is mainly a result of the reduced amount of moving parts within the EV drivetrain and the omission of fuel and exhaust gas treatment systems. Less specialized workers are able to be substituted by autonomous robots, but these must be monitored and maintained by more specialized staff. The overall increased productivity is accompanied by increased demand in a higher skilled workforce, but there is an overall reduction in the total required labor force (Bauer, Riedel, Herrmann, Borrmann, & Sachs, 2018). Nonetheless, EV production and its associated infrastructure poses an opportunity to generate additional jobs in Mexico, despite the steadily decreasing labor market of the automotive industry. The demand for EVs is increasing due to worldwide efforts to mitigate the negative consequences of transport sector emissions on health and the environment. Given its global standing in automotive manufacturing as the third largest exporter of light vehicles, Mexico is uniquely placed to invest in the production capacity of EVs. In taking a proactive approach to EV manufacturing investments, Mexico could acquire a substantial share of the global EV manufacturing market, as all other major manufacturers move to invest to be competitive in the future market (Bauer et al., 2018).

4.3 Improving energy security through EVs

4.3.1 Methodology

The indicator used to assess energy security in this analysis is the amount of reduced gasoline imports in Mexico. For the purpose of this calculation, it is assumed that EVs sold in Mexico effectively replace sales of ICEVs that would otherwise have taken place.

To determine the amount of fuel saved by the EVs, the following method was employed. The number of vehicles per class was derived from the product of the vehicle class share (%) and the total amount of vehicles registered, in 2017. The ICEVs fuel usage was based on average fuel efficiencies per vehicle of the 2016 vehicle fleet and the current average vehicle utilization per vehicle type in the Mexican transport sector. Data on these parameters can be seen in Table 8.

The analysis is based on the assumption that gasoline use of ICEVs is replaced by domestically produced electricity that powers the EVs. In turn, the amount of gasoline reduced by EVs directly reduces the amount of gasoline required to be imported into Mexico.

The EVs are divided into the following vehicle classes[11]:

Table 8: Vehicle classes used in analysis

| Electric vehicle category	Vehicle utilization	Average demand	Vehicle efficiency
	[km/year]	[kWh/km]	[km/l]
Motorcycle	10,000	0.113	36.14
Micro car (3 or 4 wheels)	15,000	0.259	18.06
Compact	17,000	0.179	16.19
Mid-size	17,000	0.160	14.00
Full-size (SUV)	17,000	0.211	9.89
Plug-in	8,500	0.201	14.00

Note: Full details on the fuel efficiencies, vehicle utilization and vehicle sales are provided in the Annex.

4.3.2 Results

Figure 25 shows the total fuel savings that would be generated by EVs as a percentage of the total gasoline use by ICEVs in Mexico per year. As can be seen in the graph, implementation of the NDC-compatible scenario is able to reduce gasoline demand for vehicles in Mexico by almost 1% in 2030. When considering the 30/30 scenario, this value increases to just over 5%.

[11] Vehicle categories and vehicle utilization were determined with the support of CMM.

Figure 25: Annual gasoline savings (%) relative to forecast gasoline demand from 2019 to 2030 (as % of projected BAU gasoline use for motor-carriers)[12].
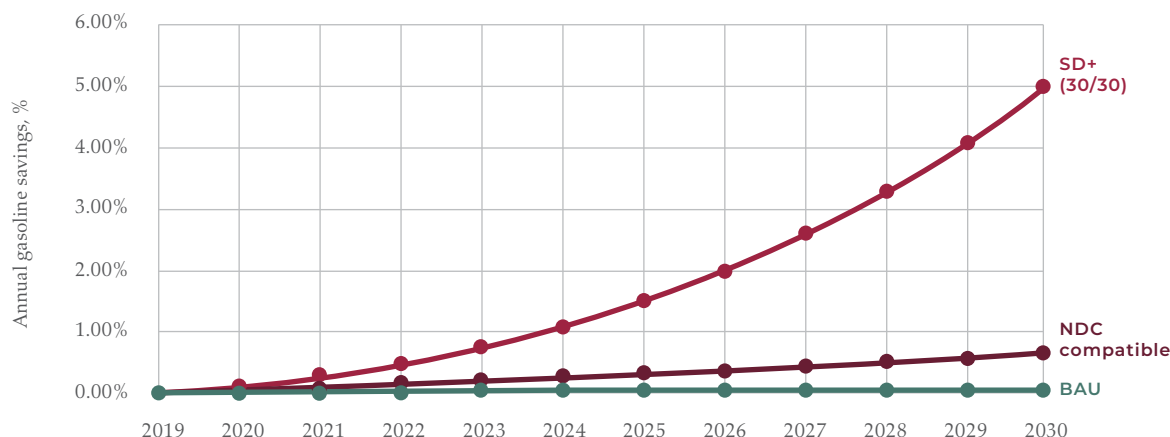
[12] Projected BAU gasoline use is based on (SENER, 2016a)

4.3.3 Discussion

The introduction of EVs in the NDC-compatible scenario could result in a 0.7% reduction of total gasoline demand for passenger vehicles in 2030. In the 30/30 scenario, these savings are a considerable 5.0%. The significance of this result should not be underestimated. In 2017, Mexico imported more than twice as much gasoline as was domestically produced (89% of which was imported from the U.S.) (PEMEX, 2019b). Domestic production shows steady decline, with imports rising to meet demand. In light of the recent fuel shortages, EVs offer an option to curb Mexican dependence on imported gasoline for transport, by substituting gasoline for domestically produced electricity. Securing the future of Mexico's energy supply can also contribute to the achievement of SDG 7 for Affordable and clean energy, in particular SDG target 7.1, to "ensure universal access to affordable, reliable and modern energy services" (United Nations, 2019, p. 8).

TARGET   7·1

UNIVERSAL ACCESS TO MODERN ENERGY
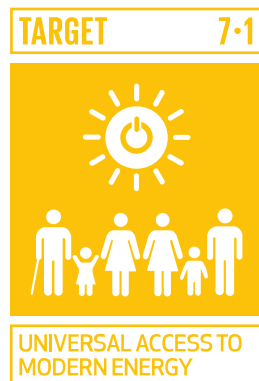
Displacing gasoline use obviously requires an increase in electricity production in order to power the EVs. The additional electricity demand in 2030 from the 500,000 EVs on the road amounts to 1,140 GWh. The additional electricity demand to power the 3.67 million vehicles of the 30/30 scenario in 2030 scenario amounts to 8,382 GWh. The theoretical potential of intermittent renewables (PV, wind, biomass, etc.) in the country is more than sufficient to provide the additional electricity demand in both scenarios. Based on current

projections of the BAU electricity mix, approximately 34,000 GWh would be injected to the grid in 2030. The total potential for intermittent renewable generation is estimated at 89,000 GWh in 2030. Therefore, this leaves an additional capacity of 55,000 GWh (between 6 and 48 times the EV electricity demand) which could be used to power the EVs with renewable electricity.

4.4 Improving public health through EVs

4.4.1 Methodology

The primary indicator used to assess this co-benefit is the amount of $PM_{2.5}$ emissions. The analysis concentrates only on impacts during the use phase[13] of EVs, and the amount of $PM_{2.5}$ emissions are calculated using the following method:

Firstly, the total amount of electricity required to power all of the EVs in the country was calculated based on the sales penetration rate, average distance travelled, and estimated electricity demand. These were all determined per vehicle class. In order to accurately portray the Mexican vehicle fleet, the following vehicle classes have been defined: Motorcycle, Micro car (3 or 4 wheels), Compact, Mid-size, Full-size (SUV), Plug-in. All vehicle classes have characteristic fuel efficiencies, vehicle utilization and emissions, which can be reviewed in the Annex.

Using this information and data on $PM_{2.5}$ emissions from Mexico's current electricity mix, the total amount of PM stemming from the electricity generation for EVs was determined. Subsequently, these emissions were compared to the $PM_{2.5}$ emissions that would result from the same number of ICEVs on the road. Data for the individual vehicle classes is based on 2016 model vehicles available on the Mexican market. It is thus effectively assumed in this calculation that the sale of EVs directly displaces sales that would otherwise have been ICEVs.

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[13] Lifecycle analyses of EVs consider 4 main phases: 1) Raw materials stage; 2) Production stage; 3) Use stage; and 4) End-of-life stage (European Environment Agency, 2018). For EVs we consider the use phase to include the electricity generation required in order to charge them.

Air pollution imposes elevated risk of contraction of noncommunicable diseases, which are responsible for 71% of all deaths globally each year.

No fuel efficiency or emission improvements are considered for the ICEVs beyond the 2016 values. The PM emission factors for the ICEVs were provided by INECC and obtained using the MOVES-Mexico model.

4.4.2 Results
The results from this analysis show that, during their operation, when powered by the current electricity mix, EVs do not contribute to an overall reduction of $PM_{2.5}$ emissions, but rather to a considerable increase. The underlying reasons for this result are discussed in the following section. The discussion also examines the possible benefits associated with this measure in terms of redistributing $PM_{2.5}$ emissions away from urban centers, and considers the key actions required to harness the potential for EVs to generate $PM_{2.5}$ emissions benefits.

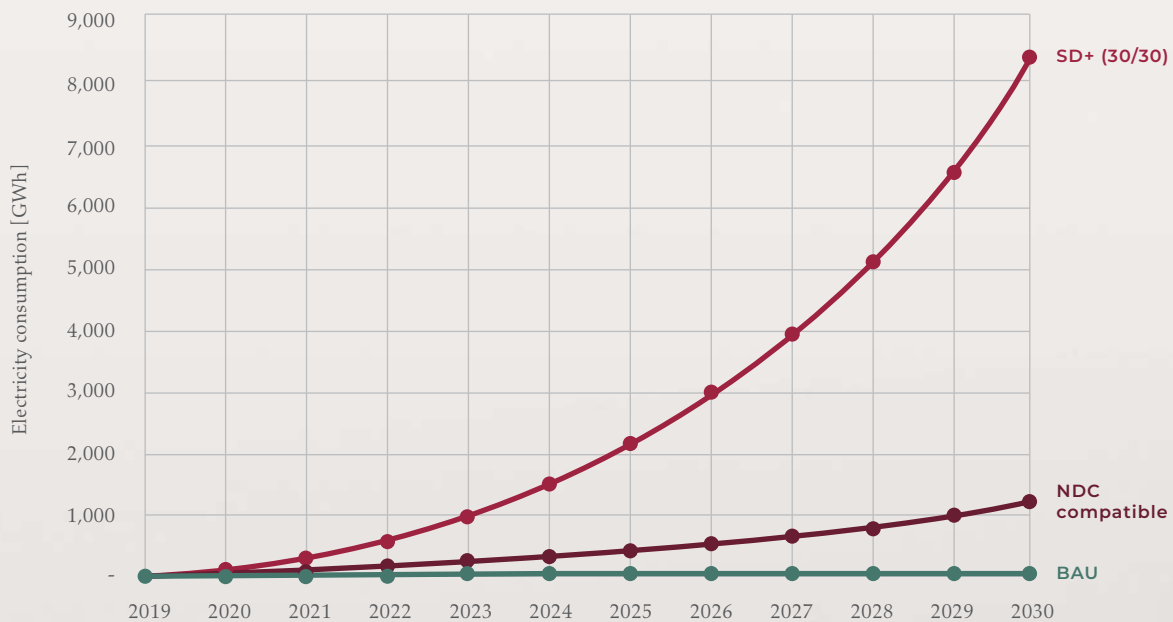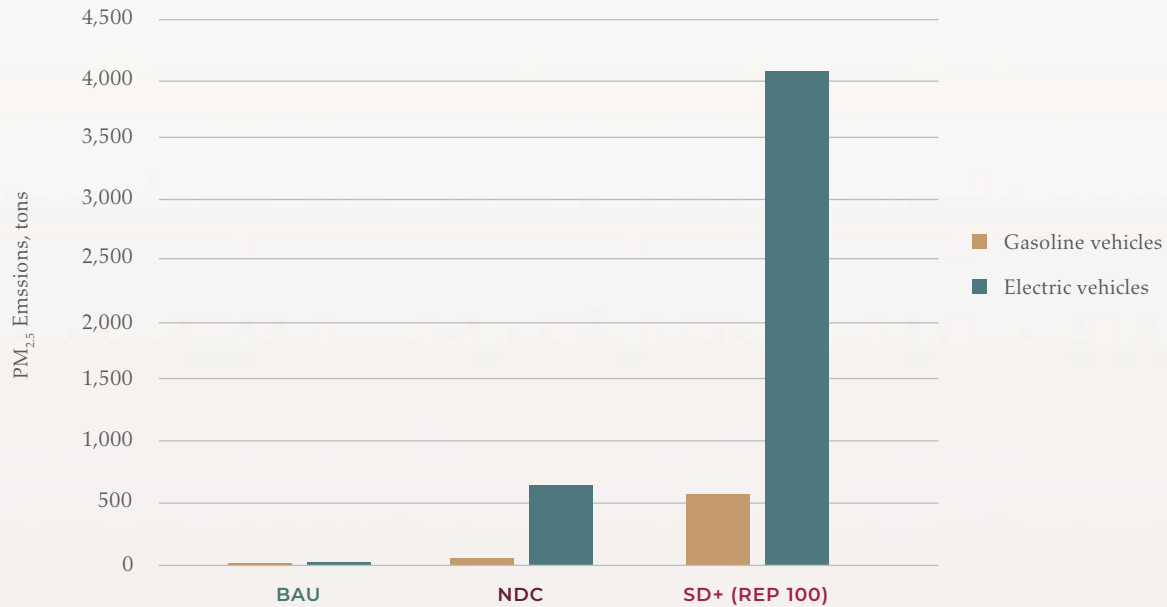**Figure 26:** Cumulative electricity consumption from EVs, 2019 to 2030.

Figure 27: $PM_{2.5}$ emissions from EVs and alternative gasoline vehicles (2019 to 2030).

4.4.3 Discussion

EVs can contribute to the decarbonization of the transport sector. However, in order to capitalize on this mitigation potential, certain supplementary conditions have to be met. The impacts of EVs are maximized when high-use vehicle fleets, such as corporate fleets and car-sharing vehicles and heavy vehicles, are powered by electricity from clean and renewable sources. Furthermore, technological advances in battery production are needed to reduce life-cycle emissions in the production stage. The achievement of Mexico's NDC-compatible target of 500,000 EVs sold by 2030, results in a 765 kt reduction of CO_2-e emissions from the BAU scenario. Increasing ambition to the 30/30 scenario results in a much larger 5,844 kt CO_2-e reduction from BAU. This, however, is a relatively small reduction, compared to other possible mitigation measures in the transport sector.

The results show that $PM_{2.5}$ emissions during the use phase of EVs – powered by the current elec-

tricity mix – are greater than those of gasoline vehicles. A primary reason for this stems from the relatively high PM missions resulting from conventional thermal generation using fuel oil (combustóleo) in Mexico.

In order to create benefits with respect to total $PM_{2.5}$ emissions in the use phase of EVs, $PM_{2.5}$ emissions of the electricity sector would need to be reduced by 87% from 0.1230 to 0.0165 ton/GWh. This level is achievable. In 2016, Germany reached a PM_{10} emission factor of the electricity generation of 0.015 ton/GWh (Umwelt Bundesamt, 2018).

The analysis in this chapter considers PM emissions associated with the fuel supply of EVs (electricity). However, it does not incorporate the PM emissions related to the extraction and processing of the fuel required for ICEVs (gasoline). This, therefore, also leads to an underestimation of the PM emissions of ICEVs and could considerably shift the results.

Research shows that EVs provide positive health benefits by shifting emissions away from densely populated areas. Case studies in Belgium and Barcelona show that public health has been improved through the introduction of EVs and subsequent reduction of exposure of people to harmful PM (European Environment Agency, 2018). The harnessing of these potential benefits would also serve towards the achievement of SDG 3 Good health and well-being targets 3.9, to "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" and 3.4 to "reduce by one third premature mortality from non-communicable diseases through prevention and treatment […]" (United Nations, 2019, pp. 3-4).
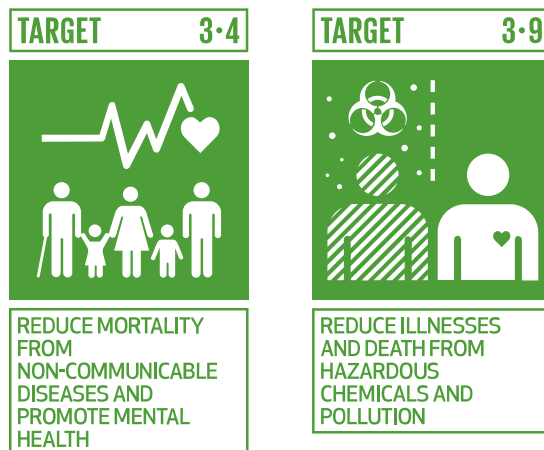
Powered with electricity from renewable energy sources, EVs can completely eliminate GHG emissions during their operation. The only GHG emissions associated with the vehicles would then be during their production and manufacturing, the extraction and refining of their required materials, in particularly those related with battery production, and recycling phases, which are dependent on the utilized technologies.

The results build a compelling case for reducing GHG and PM emissions from electricity generation in Mexico, which is a precondition for truly greening the transport sector through electric vehicles. In order to harness the full potential for EVs to deliver on $PM_{2.5}$ emissions reductions, the same stringent PM standards that are currently applied to gasoline vehicles emissions should be applied to the electricity generation sector.

It is important to consider that this analysis only examines emissions in the use phase and does not consider PM emissions in the raw materials, production or end-of-life stages, which illustrate a more complete comparison between PM emissions resulting from EVs and ICEVs.

5 SUMMARY AND OUTLOOK

EVs have the potential to reduce local air pollution in urban areas in Mexico, contributing to SDG 3 (Good health and well-being). In order to maximize this potential, a distinct shift towards renewably produced electricity must occur. The importance of low-carbon electricity is a theme that has impacts across all life cycle stages of EVs. Low-carbon electricity will change the environmental impacts associated with raw material extraction and vehicle and battery production, which could position EVs more favorably than present over ICEVs.

The integration of EVs onto Mexico's roads can additionally contribute to reduced gasoline imports and energy security in the country. Annual gasoline demand of motor vehicles could be reduced by as much as 5% in 2030, contributing to SDG 7 (Affordable and clean energy). The additional electricity demand of both the NDC-compatible and more ambitious scenarios investigated can be comprehensively covered by the renewable energy potential in Mexico. Furthermore, in creating a modest amount of employment in Mexico, EVs can also support the achievement of SDG 8 (Decent work and economic growth).
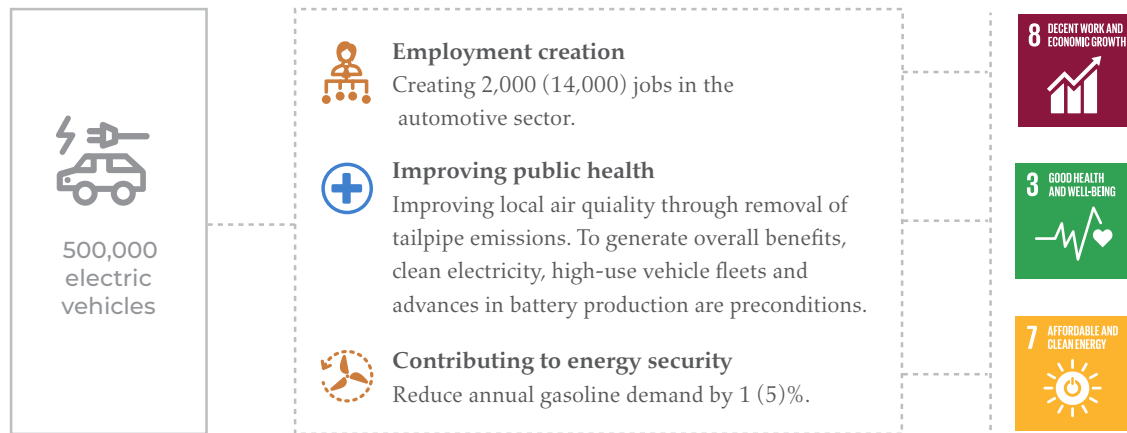
EVs are not a panacea for all of the deficiencies of Mexico's transport system, and other measures exist in the transport sector with greater mitigation potential. Significant attention needs to be directed to improving the capacity and quality of Mexico's public transportation networks, as well as freight, rail and aviation transport. Incentives for modal

shifts from private vehicles to public transport and electrifying public transportation would go a long way to reducing urban PM emissions and the health impacts associated with them.

The market for EVs is expected to significantly grow in the future, driven by reducing production costs (particularly for the main cost component, the battery) and increasing vehicle ranges. The majority of car manufacturers have announced new electric or hybrid models to comprise larger shares of their business in the coming years. Some major car companies have also already announced the end of the development of their ICEVs within the next decade (Volvo: 2019, Volkswagen: 2026). Mexico is uniquely placed to invest in the production capacity of EVs. In taking a proactive approach to EV manufacturing investments, Mexico could acquire a substantial share of the global manufacturing market, as all other major manufacturers move to invest to be competitive in the future market.

Figure 28: Summary of co-benefit results and links to SDGs stemming from EVs prospective NDC measure.

500,000 electric vehicles

Employment creation
Creating 2,000 (14,000) jobs in the automotive sector.

Improving public health
Improving local air quiality through removal of tailpipe emissions. To generate overall benefits, clean electricity, high-use vehicle fleets and advances in battery production are preconditions.

Contributing to energy security
Reduce annual gasoline demand by 1 (5)%.

8 DECENT WORK AND ECONOMIC GROWTH

3 GOOD HEALTH AND WELL-BEING

7 AFFORDABLE AND CLEAN ENERGY

5

DRIVING DEVELOPMENT BY INCREASING THE ENERGY EFFICIENCY OF MEXICAN INDUSTRY

KEY FINDINGS

- Improving energy efficiency contributes to reducing air and water pollution, improving public health and reducing the impact of energy bills on households. It also creates employment and increases energy security through the reduction of imported fossil fuels.
- Industrial energy efficiency can be a serious driver of economic development and it supports the achievement of **SDG 8** (Decent Work and Economic Growth). Implementation could create:
  - » More than 9,000 direct jobs in Mexico in the NDC-compatible scenario and;
  - » Over 154,000 jobs in the SD+ scenario.
- Energy savings improve energy security in the country by 0.2% in the NDC-compatible scenario and 7% in the SD+ scenario. These savings support the achievement of **SDG 7** (Clean and Affordable Energy). In the simulated scenarios, total energy savings are equivalent to the annual power consumption of:
  - » 780,000 Mexican households in the NDC-compatible scenario; and
  - » 11.4 million households in the SD+ scenario.

With the continuous development of innovative energy-efficient components, wasting energy through outdated technologies increases production costs of Mexico's industry and reduces competitiveness in global markets. With the aspired future growth of Mexico's industrial sectors, the introduction of energy and cost-saving components can also significantly contribute to reducing Mexico's carbon emissions.

This chapter focuses on the co-benefits of implementing energy efficiency measures in Mexico's industrial sector, with emphasis on energy security and employment creation. As energy demand is growing worldwide, energy efficiency is becoming a centerpiece in the transition to a sustainable economy (IEA, 2018). It can be defined as the "[…] amount of output that can be produced with a given input of energy" (Erbach, 2015, p. 2). Beyond its mitigation benefits, energy efficiency can generate a range of co-benefits relating to social, economic and environmental development objectives (International Energy Agency [IEA], 2018.; Office of the Presidency et al., 2018). Beyond its mitigation benefits, energy efficiency can generate a range of co-benefits relating to social, economic and environmental development objectives (International Energy Agency [IEA], 2018; Office of the Presidency et al., 2018). The selected target serving as a basis for the analysis constitutes the reduction of energy demand in the three most energy-intensive industrial sectors: cement (by 1.8%), iron and steel (by 9.6%) as well as chemical (by 14.7%) by 2030. These targets are adopted from two studies on industrial energy efficiency measures (CONUEE, 2018; Centro Mario Molina, 2017).

1 BACKGROUND: ENERGY EFFICIENCY IN MEXICO

To stabilize the growth of Mexico's short- and medium-term energy consumption, the 'Energy Transition Scenario' proposes energy efficiency measures to bring about structural change in industrial processes, expanding electric infrastructure and im-

proving buildings' long-term energy performance. More specifically, key components to reducing energy demand include: 1) enhancing the energy efficiency of new systems and equipment, 2) improving and expanding industrial recycling processes, 3) substituting current equipment with high-efficiency technologies throughout commercial and industrial sectors, 4) increasing the utilization of urban public transport while reducing the use of individual units, and 5) electrifying all means of transportation as much as possible (CONUEE & SENER, 2017).

Mexico's overarching emissions target is to reduce GHG emissions of its industrial sector by 4.8% in 2030, relative to 2030 BAU projections (INECC, 2018). The sectors with the highest potential to reduce energy consumption are transportation (50%), industry (41%) and buildings (35%) (APEC Energy Working Group, 2017). Of these, the industrial sector is the largest electricity consumer. Electricity was the second major source of energy in the industrial sector in 2015, accounting for 34% of total industrial energy demand. It is expected to become the sector's main source of energy by 2050 (CONUEE & SENER, 2017). Specific measures to increase energy efficiency across industries include substituting inefficient equipment and systems in manufacturing processes, implementing energy management systems, optimizing product design to reduce the use of raw materials, recycling industrial residue, leveraging cogeneration potentials for heat and power as well as developing energy performance standards for equipment and systems.

The energy efficiency strategy proposed by the government was established in terms of a rate of reduction in the intensity of final energy consumption: an annual average rate of 1.9% for the period 2016-2030 as an intermediary goal, and an annual average rate of 3.7% for the period 2031-2050 as the final target (CONUEE & SENER, 2017).

2 ENERGY EFFICIENCY FOR EMISSIONS MITIGATION

By 2040, annual global energy-related emissions

could be reduced by 3.5 Gt CO_2-e (12%) compared to 2017 levels. This would deliver more than 40% of the abatement required to meet the targets of the Paris Climate Agreement (IEA, 2018). Estimates suggest that energy efficiency measures can generate global energy savings of up to 23% by 2040, compared to the current policy trajectory. In 2040, the industrial sector specifically is expected to reduce global energy demand by approximately 6%. Cumulative energy savings from the industrial sector up to 2040 would amount to 390 EJ (IEA, 2018).

In Mexico, industrial processes and the use of products are responsible for 7.9% of the country's total GHG emissions (SEMARNAT & IN-ECC, 2018). Energy consumption in the industrial sector could be reduced by as much as 41% by 2050 (APEC Energy Working Group, 2017). Achieving the selected targets can generate significant mitigation benefits by 2030. Currently, no specific energy efficiency measure is included in Mexico's NDC commitment. Thus, the adoption of energy efficiency targets in the industrial sector provides an opportunity for increasing the ambitiousness of Mexico's NDC review.

3 ENERGY EFFICIENCY AS A DRIVER OF MEXICO'S DEVELOPMENT

Several studies have highlighted important co-benefits that can be expected from implementing energy efficiency measures in the industrial sector, which is also tied to SDG 7 (Affordable and Clean Energy). Some examples include reducing air and water pollution (Zhang et al., 2016), improving public health (Buonocore et al., 2016), creating employment opportunities, reducing energy costs, especially at household level, as well as increasing energy security by reducing dependency on fossil fuel imports (Federal Ministry for Economic Affairs and Energy [BMWi], 2011; IEA, 2018; Office of the Presidency et al., 2018). However, the multiple benefits of energy efficiency are often underestimated. As seen in Figure 29 below, linkages can be drawn between the industrial energy efficiency measures and the following social, environmental and economic co-benefits.

Figure 29: Full range of co-benefits induced by the industrial energy efficiency prospective NDC measure (SD Strategies, based on analysis from Office of the Presidency et al., 2018). The selection of CBs to be quantified is highlighted.
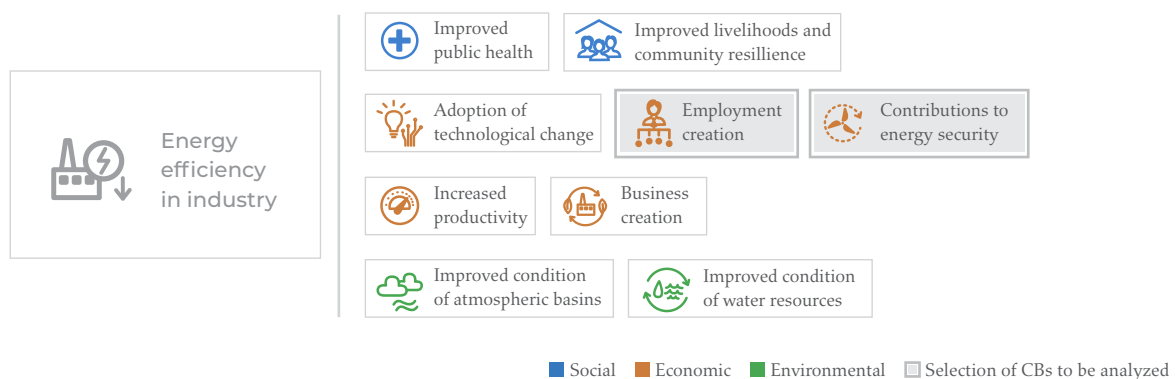
3.1 Social co-benefits

Energy efficiency measures can significantly improve public health by reducing energy-related emissions and harmful substances for industrial processes.

Globally, nearly 3 million people every year die prematurely due to factors linked to poor outdoor air quality, such as cancer, respiratory illnesses and heart disease (IEA, 2016). Successfully implemented energy efficiency measures can limit the growth

in premature deaths by reducing the concentration of energy-related particulate air pollution, such as Sulphur dioxide (SO_2) emissions, nitrogen oxides (NOx) and fine particulate matter ($PM_{2.5}$). Through reductions of coal use in the industrial and building sectors and oil use in the transport sector, SO_2 emissions could be reduced by 42% in 2040 compared to 2015 levels. $PM_{2.5}$ emissions could also be reduced by 15% as less coal is combusted for heating and power (IEA, 2018).

3.2 Economic co-benefits

Improving energy efficiency can generate several direct and indirect economic co-benefits, in areas such as productivity, employment and business creation as well as individual and business earnings. Several case studies in Mexico (CONUEE, 2019), as well as its national program for energy management systems 2013-2018 (CONUEE & SENER, 2019) have identified the benefits of energy efficiency measures for the Mexican industry in terms of reduced costs and increased productivity. In the U.S. alone, nearly 2.25 million people are employed in the energy efficiency sector. In comparison, only half as many people worked in all fossil fuel sectors combined. With a net increase of 67,000 jobs, the U.S. energy efficiency sector is the fastest growing sector in the country (IEA, 2018). On a global level, over one million energy efficiency jobs are predicted for 2030 (Rutovitz & Atherton, 2009). Furthermore, increased energy efficiency can address energy affordability and accessibility, especially in developing countries. In Mexico, it is estimated that approximately 10% of per capita household energy expenditure savings were attributable to energy efficiency measures between 2000 and 2017 (IEA, 2018). Energy efficiency can help reduce dependency on imports such as oil and gas as well as coal by reducing the overall needs of these commodities, which in turn increases energy security. Many IEA countries and other large economies have made significant gains since 2000 that have resulted in the avoidance of over 20% of fossil fuel imports in

2017. In the IEA countries alone, the value of this was estimated at over USD 30 billion. Reducing imports also entails other macroeconomic benefits, such as increasing national competitiveness and improving the balance of payments (IEA, 2018). Energy efficiency measures are able to deliver on increased productivity, often measured in terms of GDP per unit of energy consumed. Globally, the energy productivity bonus[14] amounted to around USD 2 trillion in 2017 (IEA, 2018).

3.3 Environmental co-benefits

The use of conventional energy sources entails emissions of a number of GHG emissions that contribute to inter alia the acidification of rainfall, which subsequently negatively affects water resources. GHG emissions that induce acidification include SO_2, NOx and hydrocarbons, with SO_2 being the most significant contributor. Most SO_2 emissions arise from the burning of fossil fuels in power stations. Hydrocarbons, Nitrogen and Sulphur oxides fall near their source as dry deposits, causing harm to building materials, trees and crops. High concentrations of these oxides lead to the production of sulfuric and nitric acids in reaction to sunlight, which dissolve in clouds and fall as acid rain, potentially at long distances from their source. These wet deposits increase the acidity of soil and water courses, release toxic metals from their compounds, and harm the plants and animals exposed to them. Maximizing energy efficiency, thus reducing demand for fossil fuel-based power, can reduce the release of GHG emissions that contribute to acid rain and its subsequent impacts on the condition of water resources and broader ecosystems.

4 ANALYSIS OF SELECTED CO-BENEFITS OF INDUSTRIAL ENERGY EFFICIENCY TARGETS

[14] The energy productivity bonus is defined as "[…] the difference between actual GDP and the notional level of GDP that would have been generated had energy intensity stayed at the previous year's level" (IEA, 2018, p. 34).

Maximizing energy efficiency, thus reducing demand for fossil fuel-based power, can reduce the release of GHG emissions that contribute to acid rain and its subsequent impacts on the condition of water resources and broader ecosystems.

Although energy efficiency in the industrial sector is not explicitly highlighted in Mexico's NDC, it identifies industrial processes and product use as a key component of its mitigation commitment. Industrial energy efficiency has a great potential regarding both emissions mitigation and economic gain. Therefore, its inclusion in the upcoming NDC review could be considered.

4.1 Applied scenarios and selected co-benefits

The following analysis focuses on two key co-benefits of energy efficiency measures in the industrial sector, namely, employment creation and energy security. Three scenarios are considered. These are:
1. Business as usual (BAU)
2. Nationally determined contribution (NDC-compatible)
3. SD+

For each of the three examined industrial subsectors, an NDC-compatible and a more ambitious (SD+) scenario for energy demand reduction are employed, relative to a business as usual (BAU) scenario. The details and source of the targets are shown below.

BAU
The business as usual scenarios are adopted from the two studies used as a basis for the NDC-compatible and SD+ scenarios (CONUEE, 2018; Centro Mario Molina, 2017). They are based on historical data of energy consumption and national forecasts by SENER, CONUEE. Further detail on the basis and data used for the BAU scenarios can be found in the Annex.

NDC-compatible
The NDC-compatible scenario is defined as such because it adopts targets from a study by CONUEE, which proposed a set of instruments to facilitate energy efficiency measures in Mexico's industrial sector (CONUEE, 2018).

SD+
The SD+ scenario includes significantly elevated energy savings targets based on supplementary and different measures from both CONUEE and CMM.

Table 9: NDC-compatible energy demand reduction scenarios for the three most energy-intensive industrial sub-sectors in Mexico.

Sub-sector	Iron and steel	Cement	Chemical
Energy demand reduction target (% relative to 2030 BAU)	9.6	1.8	14.7
Scenario	Implementing only selected measures* from CONUEE report with positive cost-benefits	Implementing all measures* from CONUEE report (all have positive cost-benefits)	Implementing selected measures* from CONUEE report with positive cost-benefits

*Note: The specific measures implemented to achieve each of the energy demand reduction targets can be found in the Annex.

Table 10: SD+ energy demand reduction scenarios for the top three energy-intensive industrial sub-sectors in Mexico.

Sub-sector	Iron and steel	Cement	Chemical
Energy demand reduction target (% relative to 2030 BAU)	16.1	9.1	51.8
Scenario	SD+ scenario, implementing all 4 measures* in CONUEE report, still with overall positive cost-benefit	SD+ scenario, using measures* from CMM	SD+ scenario, using measures* from CMM

*Note: The specific measures implemented to achieve each of the energy demand reduction targets can be found in the Annex.

4.2 Employment creation from industrial energy efficiency measures

4.2.1 Methodology

Assessment of the employment creation potential of energy efficiency measures in the industrial sub-sectors is based on the EFA[15]. The employment factor approach is a well-established and simple method that allows for the total employment creation of an energy efficiency intervention to be estimated. The calculation is based on factors that specify the number of jobs created (per sector) through the saving of a unit (GWh) of energy. For the industrial sector, a constant employment factor of 0.27 jobs per GWh is adopted. This value is based on a study that determined the employment occurring as a result of energy efficiency investments in the U.S. (ACEEE, 2008). The value was then trans-

lated to an employment factor in the form of jobs per GWh (Rutovitz & Atherton, 2009). The indicator used to assess employment creation is the number of direct jobs (in person-years), in development, construction, manufacturing, operations and maintenance and fuel supply.

Employment factors tend to decline with technology maturity and labor productivity. No decline factors have been applied to the employment factors due to the wide range of energy efficiency measures that are included. A regional job multiplier and local manufacturing factor are used to reflect the varying labor productivities in different countries and to translate Organization for Economic Co-operation and Development (OECD) values into Mexico-specific results. The regional job multiplier used is

[15] The methodological approach for this analysis is based on Rutovitz & Atherton (2009).

a factor of 2.15 and the local manufacturing factor is 1. Any job losses resulting from the industrial energy efficiency measures are also not included in this analysis.

The following calculation is performed on a year-by-year basis from 2019 to 2030:

Jobs created =

Energy saving per year $[GWh]$

$*$ *employment factor* $\left[\dfrac{jobs}{GWh}\right]$

$*$ *regional job multiplier* $[no\ unit]$

$*$ *local manufacturing factor* $[no\ unit]$

4.2.2 Results

Figure 30: Total jobs created through energy efficiency measures, 2019 to 2030, NDC-compatible scenario [person-years].
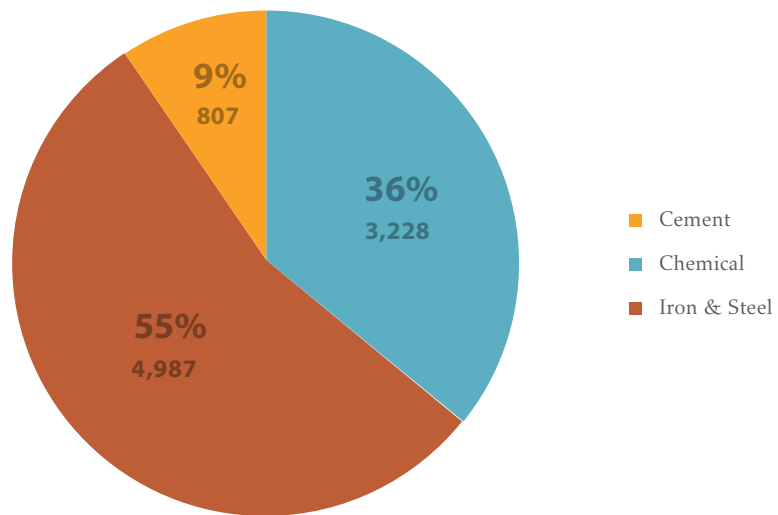
Figure 31: Total jobs created through energy efficiency measures, 2019 to 2030, SD+ scenario [person-years].
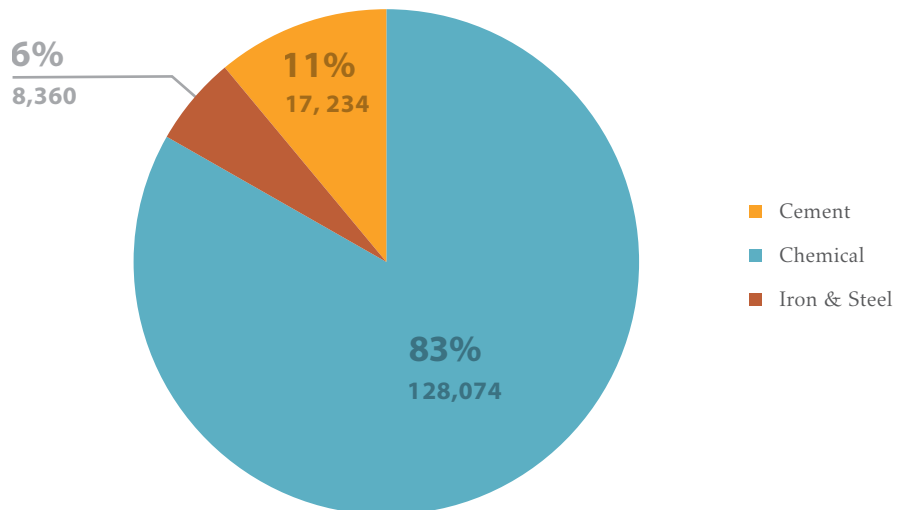
Table 11: Total jobs created through energy efficiency measures, 2019 to 2030, SD+ scenario [person-years].

Jobs created per sub-sector to 2030	NDC-compatible Scenario	SD+ Scenario
Chemical	3,228	128,074
Iron & Steel	4,987	8,360
Cement	807	17,234
Total	9,022	153,668

4.2.3 Discussion

The implementation of most energy efficiency measures also has positive cost-benefit ratios and high rates of return (Centro Mario Molina, 2017; CONUEE & SENER, 2017). The NDC-compatible energy efficiency targets have the potential to create approximately 9,000 direct jobs in Mexico. These jobs are exclusively created in the industrial energy sector in manufacturing, construction, operations and maintenance (Rutovitz & Atherton, 2009). The energy efficiency measures employed in the SD+ scenario could create more than 144,000 additional jobs in Mexico compared to the NDC-compatible scenario, mainly due to energy savings in the chemical sector. The average jobs created per year in the NDC-compatible scenario would result in a 0.17% increase in employment in the industrial sector, relative to 2018. Employment in the industrial sector would increase substantially more, by 2.9%, in the SD+ scenario.

Energy efficiency measures can contribute to the achievement of SDG 8 Decent work and economic growth. In particular, government support for innovation and growth in the energy efficiency sector can directly contribute to SDG 8 target 8.3, promoting "development oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises […]" (United Nations, 2019, p. 8). Furthermore, the employment creation can serve towards the achievement of SDG 8 target 8.5, to "achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities […]" (United Nations, 2019, p. 8).

TARGET 8·3
PROMOTE POLICIES TO SUPPORT JOB CREATION AND GROWING ENTERPRISES

TARGET 8·5
FULL EMPLOYMENT AND DECENT WORK WITH EQUAL PAY

The methodology employed to quantify employment impacts considers only direct jobs[16]. As a result of this, the method generates more conservative results of the number of jobs created than would otherwise be determined if indirect and in-

[16] The methodological approach for this analysis is based on Rutovitz & Atherton (2009).

Employment in the industrial sector would increase substantially more, by 2.9%, in the SD+ scenario.

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duced jobs were considered. The reason to focus on direct jobs was to provide a robust and clear evaluation of the job impacts from energy efficiency. It is likely that the job impacts are significantly higher than the results presented in this study, and the inclusion of indirect and induced jobs would provide a full picture of the overall employment impacts stemming from the measures. However, such an assessment is more complex and would provide less generalizable results.

4.3 Improving energy security through industrial energy efficiency measures

4.3.1 Methodology

The indicator selected to measure the impact of energy efficiency targets on energy security constitutes the amount of fuels saved in units of energy (Joule). In turn, energy security refers to the decreased dependency on imported fuels, and it is therefore assumed that savings in fuel demand directly correspond to reductions in im-

ported fuel use in Mexico.

In order to perform this calculation, the expected energy savings for each measure were determined. This was based on literature defining the energy savings of the respective measures used to achieve each of the sub-sectoral targets. For some measures, expected energy savings were already specified per fuel. However, where the fuel savings were not specified, i.e., when electricity savings was the result of the measure, the electricity savings were traced back to their generation technology. The allocation was based on the current shares of the various electricity generation technologies.

The electricity generation per technology was then split based on the fuel shares used for each technology. For example, if 100 MWh of electricity were saved, and 20% of electricity generation was based on conventional thermal generation, it was determined that 20 MWh was saved of conventional thermal generation. Then, if 50% of thermal generation comes from coal, 10 MWh of coal generation is determined as being saved.

4.3.2 Results

Figure 32: Electricity and fuel savings per sub-sector for NDC-compatible scenario (2019 to 2030).
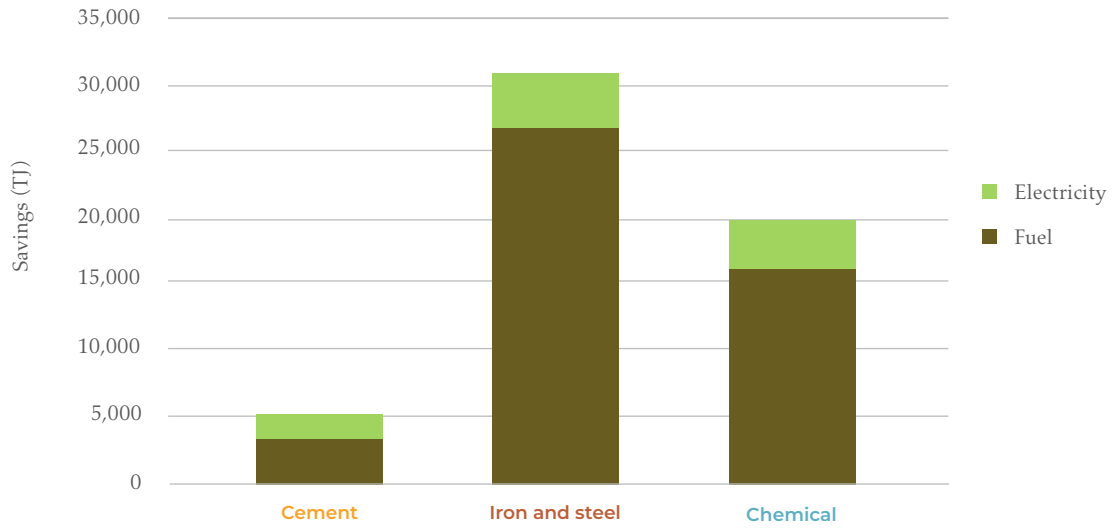

Figure 33: Electricity and fuel savings per sub-sector for SD+ scenario (2019 to 2030).
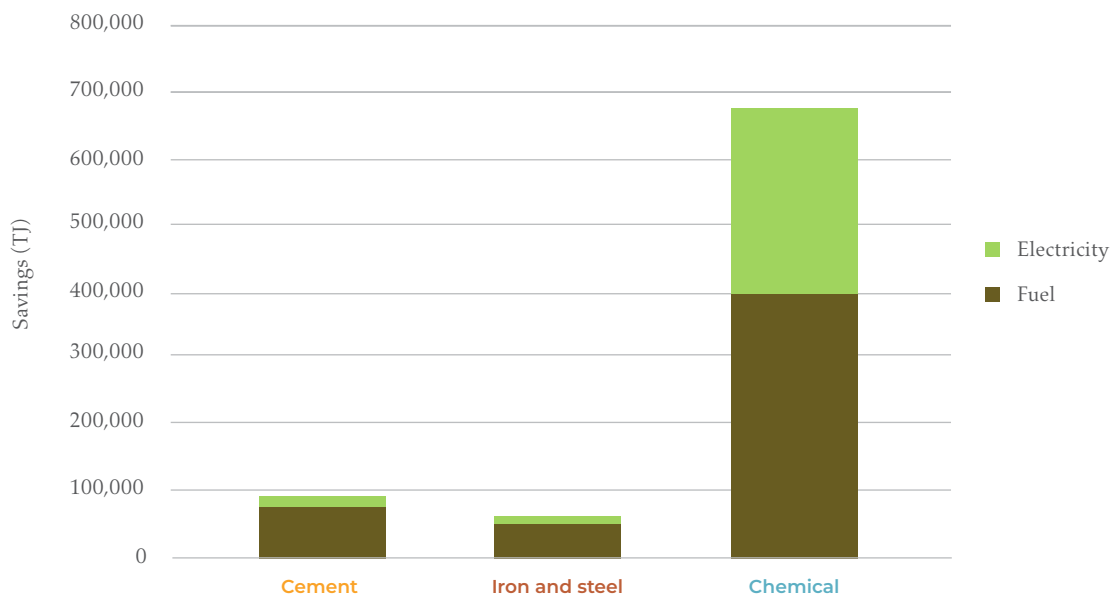
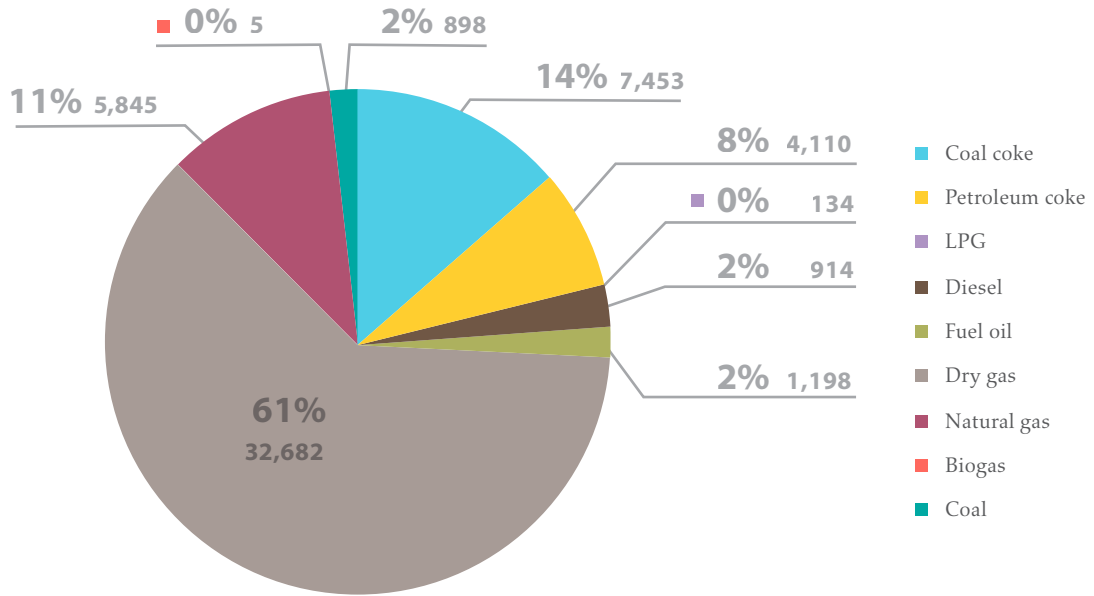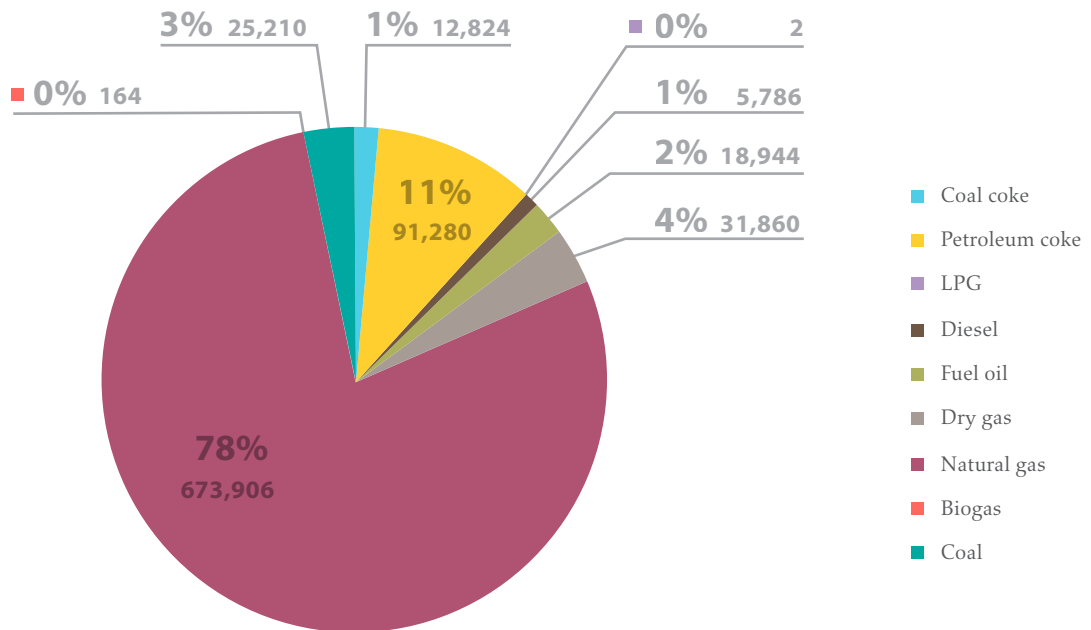**Figure 34:** Fuel savings from energy efficiency measures 2019 to 2030, NDC-compatible scenario [TJ].

Figure 35: Fuel savings from energy efficiency measures 2019 to 2030, SD+ scenario [TJ].

4.3.3 Discussion

There are significant opportunities to substantially reduce energy usage in the industrial sector, and therefore it is an appropriate sector for direct attention. However, some studies have estimated that the 5 million SMEs in Mexico could also make sizeable contributions to energy efficiency, saving 99.4 petajoule (PJ) of energy by 2030, representing 10% savings against this subsector's demands relative to BAU projections. There are concerns, however, that savings realized could be much lower in practice (CONUEE, 2018).

As displayed, implementation of the NDC-compatible scenario results in significant energy savings. The average annual fuel and electricity savings would be enough to power more than 780,000 average Mexican households (World Energy Council, 2016). In the SD+ scenario, this increases to 11.4 million households – around one third of all Mexican households (Euromonitor International, 2018).

Regarding fuel savings, the NDC-compatible scenario results in savings of 53 PJ between 2019 and 2030, compared to the BAU scenario. Achievement of the SD+ energy reduction targets generate significantly higher savings, 16 times the NDC-compatible scenario, and a total of 860 PJ. In the year 2030, total savings from the NDC-compatible scenario amount to 4.4 PJ, while for the SD+ scenario savings add up to 129.7 PJ. These savings represent 0.3% and 7%, respectively, of the fuel demand of the entire industrial sector in 2017 (SENER, 2019). The value of these savings should be considered as highly important, as they reduce Mexico's dependence on imported fossil fuels and reduce the energy demand in Mexico's industrial sector. Securing the future of Mexico's energy supply can contribute to the achievement of SDG 7 Affordable and clean energy target 7.1 in ensuring "universal access to affordable, reliable and modern energy services" (United Nations, 2019, p. 8).

5 SUMMARY AND OUTLOOK

Industrial energy efficiency provides a highly relevant opportunity for Mexico to achieve emissions mitigation, economic and social development as well as energy security. The

Implementation of the NDC-compatible scenario results in significant energy savings. The average annual fuel and electricity savings would be enough to power more than 780,000 average Mexican households.

Energy efficiency measures can reduce air and water pollution, improve public health, create employment opportunities, reduce the impact of energy bills on household budgets and increase energy security through the reduction of imported fossil fuels.
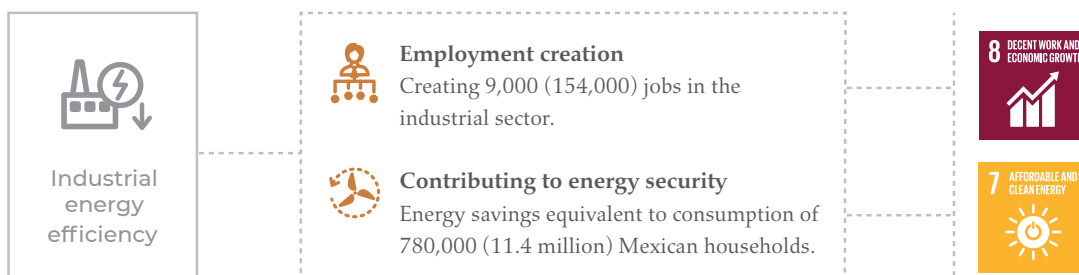
literature suggests that energy efficiency measures can reduce air and water pollution, improve public health, create employment opportunities, reduce the impact of energy bills on household budgets and increase energy security through the reduction of imported fossil fuels.

Successful implementation of the NDC-compatible scenario would result in energy savings equivalent to approximately 780,000 Mexican households. In the SD+ scenario, this number rises to 11.4 million households. These savings would reduce Mexico's dependency on imported fossil fuels in the industrial sector, hence improving energy security in the country and contributing to SDG 7.

Further, industrial energy efficiency can be a serious driver of economic development, contributing to SDG 8. The NDC-compatible scenario could create more than 9,000 direct jobs in Mexico. Achieving the SD+ targets could result in as much as 154,000 created jobs. This only considers direct jobs, including indirect and induced jobs would likely show significantly higher employment creation impacts. Future research could investigate the full impact (direct, indirect and induced) of industrial energy efficiency measures on employment creation, using economic models such as input-output tables, or measuring employment creation in relation to investments made in the sector. Also, the associated impacts on public health related to fine particulate matter ($PM_{2.5}$) could be examined, as well as more detailed analysis on the environmental impacts in air and water quality.

Figure 36: Summary of co-benefit results and links to SDGs stemming from the industrial energy efficiency prospective NDC measure.

Industrial energy efficiency

Employment creation
Creating 9,000 (154,000) jobs in the industrial sector.

Contributing to energy security
Energy savings equivalent to consumption of 780,000 (11.4 million) Mexican households.

8 DECENT WORK AND ECONOMIC GROWTH

7 AFFORDABLE AND CLEAN ENERGY

MEXICO'S OPPORTUNITY TO REAP DEVELOPMENT BENEFITS FROM CLIMATE ACTION

The traditional development discourse holds that climate action and social and economic development are not compatible. As this analysis has shown, socio-economic development for the people of Mexico is interrelated: climate action and the development agenda can be implemented in a mutually re-enforcing manner. With an effective policy implementation in mind, this co-benefit assessment report for Mexico provides a vision on the important connectors that need to be kept in mind when coordinating political agendas. The results are important for visualizing the identified development opportunities of climate action to rally support and build coalitions of action among the public and private sectors.

The purpose of this study was to determine the extent to which climate actions can generate social, economic, and environmental co-benefits beyond mitigation and adaptation impacts. and thus contributing to the implementation of the 2030 Agenda for Sustainable Development. Climate change poses an enormous threat to the people of Mexico and populations worldwide. In Mexico, people and

the environment are highly vulnerable to the broad spectrum of expected impacts as a result of unmitigated climate change. Mexico's GHG emissions have grown quickly over recent decades. Halting and reversing this trend is a priority to the Mexican government. Mexico has been a fervent supporter of international efforts to combat climate change. It has ratified the UNFCCC and supports its central goal to limit global warming to a level that does not endanger current or future populations. As part of the Paris Agreement, it has committed to an ambitious set of actions to quickly and substantially reduce its climate footprint and adapt to climatic change, communicated through its NDC.

The distinct, encouraging and imperative result from this work is that climate action can generate highly substantial development co-benefits. The importance of this finding is that climate protection and development policies can be harmonized and integrated. It means that far from opposing one another, they can support, and reinforce one another, and therefore achieve more together. Fully digesting and accepting this message has enormous

consequences. Ultimately, understanding the relationship between climate and development must result in a new development paradigm: Climate policy should be thought of as a development policy, and development strategies should be thought of crucial to climate mitigation and adaptation objectives.

The study has examined and, to the extent possible, quantified the impact of selected NDCs on specific Mexican development priorities which are also reflected in the 2030 Agenda for Sustainable Development. Three of the investigated commitments (clean electricity, net-zero deforestation, wastewater treatment) are existing NDCs, while the other two (electric vehicles and industrial energy efficiency) are potential new pledges based on recent domestic policies, strategies and ministerial input. These new pledges could be registered in an updated NDC communication from Mexico, as part of the ongoing Paris Agreement process of the UN in reviewing, and encouraging greater ambition of, climate action.

Figure 37: SDG alignment with the co-benefits stemming from the range of climate actions analyzed in the study (UN, 2019).
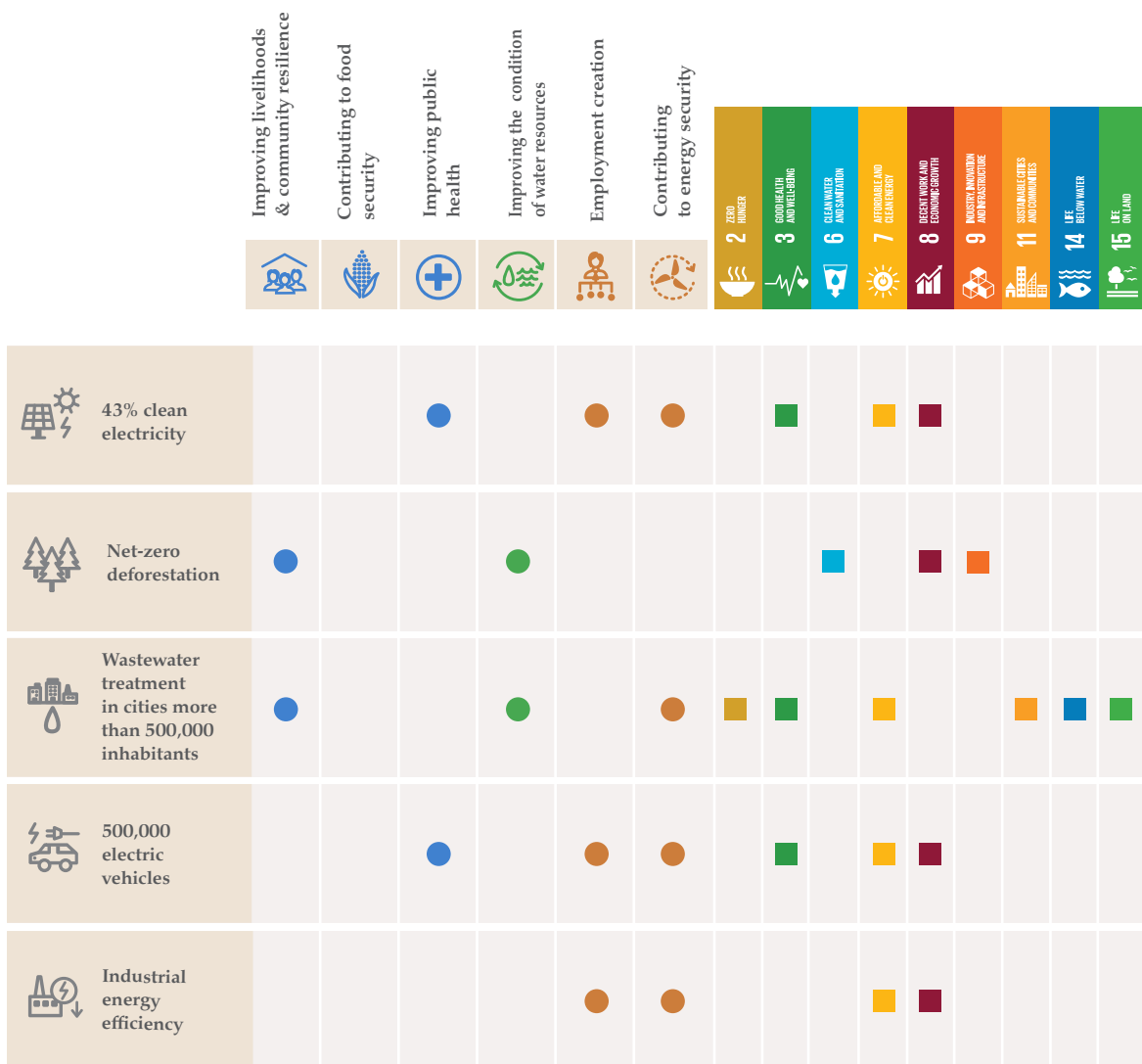
Understanding the relationship between climate and development must result in a new development paradigm: Climate policy should be thought of as a development policy, and development strategies should be thought of crucial to climate mitigation and adaptation objectives.

This research shows that the health of the Mexican population can be significantly improved by transitioning to clean energy, reducing deforestation, and improving wastewater treatment, all of which are actions highly effective for the mitigation of, and adaption to, climate change impacts. Through climate-compatible actions in these areas, a considerable number of deaths and serious illnesses can be prevented. The resulting cost savings for Mexican citizens as well as federal and sub-federal governments will also be substantial, in the order of billions (USD) annually. Further research should be undertaken to specify such initial estimates in more detail and add the sectoral or sub-sectoral numbers this work has not been able to produce.

Extensive opportunities are available for improving energy security in Mexico: this research shows a very high potential to reduce Mexico's dependency on imported gasoline (predominantly from the US), natural gas, diesel and other fossil fuels. These opportunities exist in replacing fossil fuel-based electricity generation with generation from clean sources, substituting gasoline consumption of conventional cars with domestically produced electricity through EVs, and implementing industrial energy efficiency measures.

Regarding employment, this report shows that the renewable energy and energy efficiency sectors have the potential to become serious drivers of economic growth and development: More than 100,000 jobs in Mexico could be created through the implementation of these climate actions.

Finally, all of the climate change mitigation and adaptation measures investigated showed positive impacts on the environment, in particular in improving the condition of the atmosphere and of water resources in the country. Specifically, reducing deforestation and increasing wastewater treatment made important contributions to these environmental benefits, with the latter also posing an indirect opportunity to increase agricultural production and food security in Mexico.

Overall, the co-benefits induced by the five selected climate actions contribute towards the achievement of 10 out of the 17 SDGs. These include SDG 2 (Zero hunger), SDG 3 (Good health and well-being), SDG 6 (Clean water and sanitation), SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth), SDG 9 (Industry, innovation and infrastructure), SDG 11 (Sustainable cities and communities), SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land).

This study delivers stimulating and pertinent findings for those tasked and involved in climate and development policymaking. In the process, it identified important data, research and analytical gaps that must be filled swiftly and comprehensively to inform policymaking. Immediate additional research needs to include:

- Further identification of links between NDCs, co-benefits and SDGs is needed to gain a deeper understanding of the synergies between the Paris Agreement and the 2030 Agenda.
- Determination of new methodologies to assess co-benefits of climate action and consensus among the established methodologies for measuring specific co-benefits is needed to allow for standardization of a common approach and comparison between results in different country contexts.
- Deeper analysis of employment impacts from energy efficiency, renewable energy and sustainable forestry is required to establish a more detailed scope of the potential impacts, including indirect and induced impacts.
- More sophisticated models on generation, dispersion and exposure of $PM_{2.5}$ emissions from EVs and electricity generation could ascertain the overall health impacts with more specificity.
- The extent to which wastewater treatment savings can contribute to food security should be examined, as well as more precisely establishing forests' contribution to improving the quality of water sources and economic development.

The potential of studies such as this one to guide the mainstreaming of climate and development goals is enormous. They can inform and guide the design of sectoral and cross-sectoral strategies, policies and measures – the consequences of which are paramount for the lives of all Mexican people. It must be said that research, analysis and communication of the development impacts of climate action as well as on the climate impacts of alternate development policies is still in its infancy. If we want to do a better job in integrating both – and we must if we want to achieve the goals of either agenda – our efforts must be significantly strengthened and aligned.

Examining the full spectrum of co-benefits beyond those presented in this study would illustrate the complete and vast potential for climate action to support development objectives. Mexico has an opportunity to become a global leader in climate and development policy in two ways: firstly, by actively incorporating development benefits into its climate policies and decision-making and, secondly, by mainstreaming climate goals into its national development plans and all relevant sectoral development programs from energy and transport to agriculture. Only in doing so can the country harness the full potential of the established synergies between the Paris Agreement and 2030 Agenda.

The co-benefits induced by the five selected climate actions contribute towards the achievement of 10 out of the 17 SDGs.

ANNEX 1
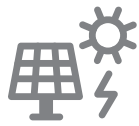
ENERGIZING MEXICO'S DEVELOPMENT WITH CLEAN SOURCES

CO-BENEFIT 1: IMPROVING PUBLIC HEALTH CALCULATION DATA.

Table 1: Data used for mortality cost calculation.

Assumptions		Source
Total mortality costs of PM$_{2.5}$ (USD/year)	327,000,000,000	(Heo et al., 2016)
Value statical life USA (USD/person)	8,600,000	
Number of deaths USA (deaths/year)	38,023	
Total PM costs range (USD/ton)	....	
›**Minimum**	88,000	
›**Maximum**	130,000	
Value statistical life MX (USD/person)	1,629,000	(Trejo-González et al., 2019)

Figure 1: Yearly social costs of PM$_{2.5}$ emissions (Heo et al., 2016).
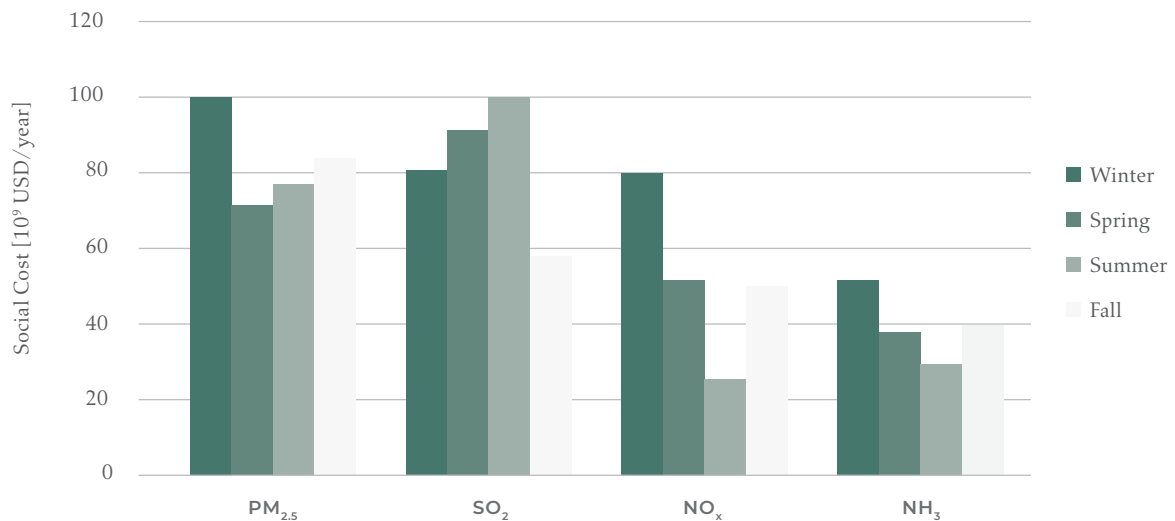
CO-BENEFIT 2: EMPLOYMENT CREATION CALCULATION DATA.

Renewable technology specifics

Table 2: Regional job multipliers.

Technology	Dispatch hours*	Capacity factor	Project years	Source
Hydroelectric	3505	40.01%	50	(Barrera, 2018)
Efficient cogeneration	4846	55.00%	15	(Gibson, Meybodi & Behnia, 2016)
Nuclear	6768	77.26%	50	(IAEA,2018)
Wind	2395	27.34%	22.5	(Morthorst & Kitzing, 2016; Ziegler, Gonzalez, Rubert, Smolka & Melero, 2018)
Geothermal	6373	72.75%	30	(SENER, 2017b)
Solar PV	1405	16.04%	30	(SENER, 2017b)
Solar thermal	1405	16.04%	27.5	(IRENA & IEA, 2013; Rodríguez-Serrano, Caldés, Rúa & Lechón, 2017)
Biomass	1827	20.86%	30	(SENER, 2017b)

Table 3: Employment factors used in job creation calculation - Based on jobs/MWp and accounted for capacity factor and project lifetime.

Technology	Manufacturing	Installation	O&M	Manufacturing	Installation	O&M	Source
	[person-years /MWp]	*[person-years /MWp]*	*[person-years /MWp]*	*[person-years /GWh]*	*[person-years /GWh]*	*[person-years /GWh]*	
Hydroelectric	5.1	0.0***	5.5	0.03	0.00	1.57	(Bere et al., 2015)
Efficient cogeneration*	3.3	8.3	0.8	0.05	0.11	0.17	(Institute for Sustainable Futures, 2015)
Nuclear	12.1	0.0***	0.6	0.20	0.00	0.09	(IAEA, 2018)
Wind**	4.0	2.0	0.3	0.07	0.04	0.13	(Ortega & Lewis, 2011)
Geothermal	4.0	0.0	1.7	0.02	0.24	0.27	(Dalton & Lewis, 2011)

Continuation Table 3:

Technology	Manufacturing	Installation	O&M	Manufacturing	Installation	O&M	Source
....	*[person-years /MWp]*	*[person-years /MWp]*	*[person-years /MWp]*	*[person-years /GWh]*	*[person-years /GWh]*	*[person-years /GWh]*	....
Solar PV**	18.8	11.2	0.3	0.45	0.27	0.21	(Cameron & Van Der Zwaan, 2015)
Solar thermal**	12.8	10.2	0.5	0.33	0.26	0.36	(Cameron & Van Der Zwaan, 2015)
Biomass	3.5	0.0	2.3	0.06	0.00	1.26	(Dalton & Lewis, 2011)

* Average of coal, gas, biomass, geothermal technology
** EFs are averages from multiple studies
*** Included in manufacturing

CO-BENEFIT 3: ENERGY SECURITY CALCULATION DATA.

Renewable technology specifics

Table 4: Conversion efficiency per technology.

Technology	Efficiency [%]	Fuel	Source	Number of plants	Source
Combustion plant	41.20%	Natural gas, diesel fuel oil	(SENER, 2017b)	248	(SENER, 2018)
Fluidized bed combustion	28.00%	Coal	(SENER, 2017b)	2	(SENER, 2018)
Coal power plant	41.70%	Coal	(SENER, 2017b)	3	(SENER, 2018)
Combined cycle	48.20%	Natural gas	(SENER, 2017b)	83	(SENER, 2018)
Gas turbine	40.05%	Natural gas, diesel	(SENER, 2017b)	131	(SENER, 2018)
Conventional thermal	38.70%	Coal, natural gas, diesel, fuel oil	(SENER, 2018)	59	(SENER, 2018)

Note: The energy saved (GWh) per scenario and technology is determined through running CMM's electricity sector model

Table 5: Conventional generation fuel shares*.

Technology	Natural gas	Diesel	Fuel oil	Coal	Biogas	Total	Source
Combustion plant	14.84%	77.74%	1.06%	-	6.36%	100%	(CRE, 2016)
Fluidized bed combustion	-	-	-	100%	-	100%	(SENER, 2017b)
Coal power plant	-	-	-	100%	-	100%	(SENER, 2016b)
Combined cycle	100.00%	-	-	-	-	100%	(SENER, 2017b)
Gas turbine	75.51%	21.77%	2.72%	-	-	100%	(CRE, 2016)
Conventional thermal	51.85%	3.70%	44.44%	-	-	100%	(CRE, 2016)

* Fuel shares derived based on the number of plants using each of the specific fuels per technology. This assumes an equal utilization of each fuel-specific generation facility.

Table 6: Energy content of fuel.

Fuel type	LHV$_{dry}$ [MJ/kg]	Source
Natural gas	46.0	(CONUEE,2017)
Coal	29.0	(CONUEE,2017)
Fuel oil	41.3	(CONUEE,2017)
Diesel	44.3	(CONUEE,2017)
Biogas	23.9	(CONUEE,2017)

ANNEX 2

PROTECTING MEXICO'S FORESTS TO SUSTAIN NATIONAL DEVELOPMENT

METHODOLOGICAL CONSTRAINTS

Net deforestation represents the difference in forest area between two points in time, measuring the losses from deforestation against the gains from forest regeneration. Fundamentally, a successful net-zero deforestation policy generates an equal or greater number of trees planted compared to trees deforested in a given time period. Between 2010-2015, Mexico saw an average annual deforestation rate of 0.2%, translating into approximately 91,700 hectares per year (FAO, 2015). Thus, according to a simplistic net-zero deforestation policy, 91,700 hectares or more of annual afforestation would be considered successful.

However, considering mere forest cover is insufficient in realizing meaningful environmental conservation, emissions abatement and socio-economic improvement. Instead, effective policy must present clear qualitative, geographic and temporal standards that dictate where, when and in what manner deforestation and afforestation can occur. It is important to evaluate the forest in terms of its carbon sequestration capacity, biodiversity, ecosystem value, cultural importance and other critical values when designing the afforestation policy.

The environmental heterogeneity of Mexico poses a methodological challenge in calculating the impacts of forestation policy across the country. It means that, even if a policy is applied uniformly across the country, effects and benefits vary widely. Thus, broader trends and benefits from a net-zero deforestation policy are explained in the report, with certain specifics of certain ecosystems highlighted when appropriate. In addition, areas of further research will be suggested to overcome such methodological hurdles in future studies.

The heterogeneity of the forest landscape further requires varying levels of protection, as certain forests may be more productive, harder to replace or more valuable than others. Under a 'weak' net-zero deforestation policy regime, a hectare of deforested rainforest could technically be replaced by a hectare of pine trees. Total tree cover change would be net-zero, however, insufficient in terms of biodiversity preservation, carbon sequestration and possibly the utility to local communities.

Policy details should reflect the underlying goals of Mexico's net-zero deforestation policy. According to the 2018 Spinning the Web report, net-zero deforestation contributes economic, social and environmental benefits through Land Use, Land-Use Change and Forestry (LULUCF) and Ecosystem-based Adaptation (EbA). The simultaneous goals of improving and conserving biodiversity, carbon sequestration, adapting to climate change, improving the condition of water resources and other objectives should be considered and weighed against one another when designing this policy.

Due to the lack of data regarding exact values of co-benefits associated with net-zero deforestation in Mexico, the analysis builds on qualitative research, outlining co-benefits to guide policymakers in forest policy decision making. Further research is needed to quantify the exact scope of these co-benefits.

COMMUNITY-BASED FOREST GOVERNANCE AND PAYMENTS FOR ECOSYSTEM SERVICES:

Historically, Mexico has been a leader and precedent-setter regarding forest policy and the net-zero deforestation target can be the continuation of this legacy. The restitution of land rights to peasants was a driver of the 1910 Mexican Revolution. Ownership of over 16 million hectares of land was transferred from elites to peasants and local communities during this time (Bray, 2013). The laws and institutions governing land ownership and governance were modified until the early 1930's, after which they have largely remained the same until today.

In Mexico and other countries, CFM has proven a successful approach to preventing deforestation and promoting sustainable governance of forest resources (Klooster & Masera, 2000; Cronkleton et al., 2011). Mexico's community governance system thus holds great potential as an enabling environment to meet the net-zero deforestation target as well as capturing co-benefits of forest services. However, CFM currently faces a number of technical and socio-economic barriers, such as lack of specialized knowledge and capital, costs, corruption, competition for domestic forest products from foreign imports, as well as clandestine Mexican logging (Klooster and Masera, 2000; Bray et al., 2006). In supporting local communities on these points, the great potential of CFM can be utilized to achieve net-zero deforestation.

The Mexican government has been implementing, expanding and improving upon Payment for Ecosystem Services (PES) programs in an effort to curb deforestation, improve environmental processes, and support rural land-using communities. The programs work under the following assumptions: Land owners do not receive many monetary and livelihood-related benefits from conservation, which incentivizes them to convert land to pastures or other utilized agricultural areas. Since deforestation imposes downstream costs on larger populations through the weakening of environmental services such as water filtration, payments for preserving forests can make conservation an attractive option for landowners and serve society at-large (Pagiola et al., 2005). In addition to the preservation of environmental services, PES programs acknowledge that many rural land owners are confronted by poverty and low income, to which these payments can improve their livelihoods and resilience through income diversification.

As a response to the lack of success of other forest preservation measures, the government initiated the Payment for Hydrological Ecosystem Services program in 2003, which was later expanded to a general Payment for Ecosystem Services (PES) program in 2006 (CIDAC 2014). Overseen by National Forestry Commission (CONAFOR), the program pays landowners and communities to sustainably manage the land to decrease degradation of forests and ecosystem services. Mexico's PES program has enrolled over 4 million hectares of land and was compensating 7,350 property owners with over $15.9 million Mexican pesos by 2017 (Alatorre-troncoso, 2014).

Mexico's PES programs have been shown to reduce deforestation by as a much as 40% in high risk areas; they had a neutral or positive effect on social capital; and they increased investment in communal infrastructure by 20-25% in communities receiving payments (SEMARNAT et al., 2017).

ANNEX 3

TREATING WASTEWATER FOR MEXICO'S PROGRESS

LOCALITIES WITH MORE THAN 500,000 INHABITANTS IN 2030

Table 7: Localities with more than 500,000 inhabitants in 2030.

No.	City	State	Population	
			2015	*2030*
1.	Acapulco	Guerrero	843,414	879,038
2.	Aguascalientes	Aguascalientes	864,687	1,003,418
3.	Atizapán de Zaragoza	State of Mexico	535,435	620,111
4.	Cancún	Quintana Roo	782,398	1,101,010
5.	Chihuahua	Chihuahua	910,505	1,013,190
6.	Chimalhuacán	State of Mexico	704,538	875,798
7.	Ciudad Apodaca	Nuevo León	601,971	760,089
8.	Mexico City	Distrito Federal	8,854,598	8,439,786
9.	Ciudad Juárez	Chihuahua	1,423,166	1,616,344
10.	Cuautitlán Izcalli	State of Mexico	556,454	640,247
11.	Culiacán	Sinaloa	938,715	1,053,580
12.	Durango	Durango	639,477	722,825
13.	Ecatepec	State of Mexico	1,760,705	2,039,602
14.	Guadalajara	Jalisco	1,506,359	1,632,307
15.	Guadalupe*	Nuevo León	700,868	806,207
16.	Hermosillo	Sonora	870,096	1,036,472
17.	Irapuato	Guanajuato	566,888	620,096
18.	León	Guanajuato	1,527,668	1,678,746
19.	Matamoros	Tamaulipas	524,951	608,825
20.	Mérida	Yucatán	897,686	1,038,488
21.	Mexicali	Baja California	1,025,740	1,210,211

Continuation Table 7:

No.	City	State	Population	
			2015	*2030*
22.	**Monterrey**	Nuevo León	1,183,171	1,352,779
23.	**Morelia**	Michoacán	767,820	822,058
24.	**Naucalpan**	State of Mexico	897,015	1,034,469
25.	**Nezahualcóyotl**	State of Mexico	1,174,479	1,334,201
26.	**Puebla**	Puebla	1,634,141	1,785,694
27.	**Querétaro**	Querétaro	863,409	1,016,031
28.	**Reynosa**	Tamaulipas	681,251	810,331
29.	**Saltillo**	Coahuila	788,039	917,077
30.	**San Luis Potosí**	San Luis Potosí	825,266	913,574
31.	**Tijuana**	Baja California	1,722,348	2,075,237
32.	**Tlajomulco**	Jalisco	540,659	683,952
33.	**Tlalnepantla de Baz**	State of Mexico	700,958	784,390
34.	**Tlaquepaque***	San Luis Potosí	652,057	758,905
35.	**Toluca**	State of Mexico	914,841	1,096,700
36.	**Tonalá**	Jalisco	531,751	630,810
37.	**Torreón**	Coahuila	692,386	798,014
38.	**Tultitlán**	State of Mexico	589,477	701,529
39.	**Tuxtla Gutiérrez**	Chiapas	613,231	697,568
40.	**Veracruz**	Veracruz	585,019	629,819
41.	**Villahermosa**	Tabasco	691,383	770,760
42.	**Zapopan**	Jalisco	1,340,283	1,535,393
43.	**Ixtapaluca****	State of Mexico	521,001	633,645
44.	**Ahome****	Sinaloa	451,782	501,125
45.	**Cajeme****	Sonora	447,677	522,849
46.	**Celaya****	Guanajuato	499,094	542,279
47.	**Ensenada****	Baja California	519,813	623,656
48.	**General Escobedo****	Nuevo León	404,169	508,307
49.	**Mazatlán****	Sinaloa	479,349	529,229
50.	**Nicolás Romero****	State of Mexico	425,137	517,003
51.	**San Nicolás de los Garza****	Nuevo León	449,553	499,418
52.	**Tecámac****	State of Mexico	444,503	553,582
53.	**Tepic****	Nayarit	429,363	541,925
54.	**Xalapa****	Veracruz	493,144	538,100

ASSUMPTIONS AND METHODOLOGY FOR CALCULATIONS

1. Wastewater available for reuse

Inputs:
- Population projection: data from CONAVI
- Wastewater generated per day: 187.5 liters per person per day (IMTA, SEMARNAT & GIZ, unpublished)
- Percentage of wastewater collected (assumption)
- Percentage of collected wastewater reused (assumption)

Calculations:
- Wastewater generated (WWG): population x 187.5 x 365
- Wastewater collected (WWC): WWG*Percentage of wastewater collected
- Wastewater available for reuse: WWC* Percentage of collected wastewater reused

2. BOD_5 removed

Inputs:
- Wastewater treated (results from own calculations)
- Percentage of wastewater reused (assumption)
- Average BOD_5 concentration in wastewater before treatment (ABDO): 270mg/L (calculation from baseline data – CONAGUA 2018a)
- Target BOD_5 concentration, water for reuse: 30 mg/L (maximum limit of contaminate allowed for reused wastewater, services to the public with indirect or occasional contact, NOM-003-SEMARNAT-1997)
- Target BOD_5 concentration, water not for reuse: 60 mg/L (maximum limit allowed of contaminants of wastewater discharged into national water bodies or properties NOM-001- SEMARNAT-1996)

Calculations:
BOD_5 removed from wastewater for reuse (DRU):
- Wastewater treated x percentage of wastewater reused x (Average BOD_5 concentration in wastewater before treatment - Target BOD_5 concentration, water for reuse)

BOD_5 removed from wastewater not for reuse (DRN):
- Wastewater treated x (1 - percentage of wastewater reused) x (Average BOD_5 concentration in wastewater before treatment - Target BOD_5 concentration, water not for reuse)

Total BOD_5 removed = DRU + DRN

Table 8: Existing wastewater treatment plants with capacity to produce biogas
Source: SD Strategies, based on (GIZ, SEMARNAT & SENER, 2018), 2019.

Plant	Starting year (energy)	Biogas production potential m³/day	Intended use of the biogas	Electricity generation capacity	Mitigation Tons of CO_2e	Comments
Agua Prieta, Jalisco	2014	n/a	Electricity	41.00 MW	29,647 during the first 15 months of operation	Can provide up to 90% of the energy required for the treatment plant operation, which in 2012 represented savings above 7 million US dollars a year.
Dulces Nombres, Nuevo León	1997	68,388	Electricity and heath	9.2 MW	24,683 (potential)	The co-generation equipment is not operational, so no electricity is being produced.
Norte, Nuevo León	1997	29,924	Electricity	1.6 MW	10,799 (potential)	No electricity being produced.
León, Guanajuato	2010	n/a	Electricity and heath	1.75 MW	-	Expected reduction of up to 75% of electricity bill.
El Ahogado, Jalisco	2012	19,195	Electricity and heath	2.83 MW	58,376 (potential)	Generates more than 60% of the electricity consumed by the treatment plant.
San Pedro Mártir, Querétaro	2010	9,018	Heath and electricity	1.05 MW	3,056/year (potential)	-
Principal, Coahuila	2008	14,210	Heath and electricity	0.86 MW	4,504/year (potential)	Expected to meet 70-80% electricity needs
Atotonilco, Hidalgo	2012	n/a	Electricity	32.6 MW	145,000/year (potential)	Expected to cover 62% of the plant's electricity needs
Hermosillo, Sonora	2016	n/a	Electricity	1.65 MW	n/a	Expected to meet 40-60% of the plant's electricity needs
Villa de Álvarez, Colima	2007	3,000	Electricity and heath	257 kWh/d	1,633 (potential)	-
La Purísima Guanajuato	2014	n/a	Electricity and heath	4,838 kWh/d	440.17 (potential)	-

ANNEX 4

BOOSTING ELECTRIC VEHICLES TO ADVANCE THE WELL-BEING OF MEXICANS

DETAILED METHODOLOGY AND ASSUMPTIONS (MODEL ASSUMPTIONS FROM CMM):

Table 9: All vehicle classes and specifics.

Electric vehicle category	Initial % of participation	Participation evolution	Vehicle utilization	Average demand	Average demand	Emissions factor		Vehicle efficiency	Gasoline consumption
....	[%]	[%/year]	[km/year]	[kWh/km]	[MWh/km]	[CO_2e g/km]	[tCO_2e/year]	[kM/l]	[l/year]
Motorcycle	6%	5.00%	10,000	0.113	1.12541	71.23	0.71	36.14	276.72
Microcar	0.5%	30.00%	15,000	0.259	3.88875	142.45	2.14	18.06	830.63
Compact	9%	9.00%	17,000	0.179	3.05007	180.85	3.07	16.19	1,050.24
Mid-size	8%	6.00%	17,000	0.160	2.72000	205.66	3.50	14.00	1,213.89
Full-size (SUV)	6%	-	17,000	0.211	3.57895	298.74	5.08	9.89	1,719.06
Plug-in*	70.5%	-5.00%	8,500	0.201	1.70765	205.66	1.75	14.00	606.95

Source: Centro Mario Molina

GENERAL INPUTS FOR ALL SCENARIOS

Initial EV Participation [%]:
• CMM estimation
Participation evolution [%/year] - % added each year compared to year before:
• CMM estimation
Vehicle Utilization [km/year]:
• According to EUROPA PRESS (2019), an electric car starts to be profitable with a minimum of 15,000 kilometers per year
• NECC sets the average distance traveled per year of 15,000 Km/year in city driving conditions
Average electricity demand per vehicle [kWh/km]:
• Motorcycle

» Av. Value of: Imobility (2019), Slane (2019), Yamaha (2019)
- Micro car (3 or 4 wheels)
    » Av. Value of: RENAULT Z.E. (2019), ZACUA (2019)
- Compact
    » Av. Value of: Chevrolet (2019), Wikipedia (2019), Nissan Leaf
- Mid-size: Wikipedia (2019) Mitsubishi i-MiEV,
- Full-size (SUV): Tesla (2019) Model X, Wikipedia (2019) Mitsubishi i-MiEV
- Plug-in*: INECC (2019), Eco vehículos

Emissions factor [CO_2e g/km]:
- Motorcycle: 0.5 * Emissions factor Micro car
- Micro car (3 or 4 wheels): Av. Value of: INECC (2019), Eco vehículos
- Compact: Av. Value of: INECC (2019), Eco vehículos
- Mid-size: Av. Value of: INECC (2019), Eco vehículos
- Full-size (SUV): Av. Value of: INECC (2019), Eco vehículos
- Plug-in*: Av. Value of: INECC (2019), Eco vehículos

Fuel demand [km/l]:
- Av. Value of: INECC (2019), Eco vehículos

https://www.inecc.gob.mx/ecovehiculos/ecovehiculos/index.html

Emission factor [$TonCO_2$e/GWh]:
- Based on CMM model to estimate electricity consumption, costs, and emissions from the electric sector in a scenario from 2018 to 2032.

Sales estimation 2019-2030:
- Based on the historical average growth rate from 2006-2017 (historical unit vehicles sales data), for total & light vehicles.
    » 3.3% total vehicles 2006-2017
    » 4.4% light vehicles 2006-2017
    » 1,580,993 total vehicles in 2018
    » 1,388,550 light vehicles in 2018

Share of EV sales of total sales:
- Based on estimation of Chevrolet, BAU 0.1%

SCENARIO SPECIFIC INPUTS

NDC compatible scenario (adopted from SEMARNAT's national electro-mobility strategy)

Electric Vehicles sales percentage scenarios: chosen to reach 500,000 EV's in 2030, consistent interpolation over 11 years to reach 4% (=500,000EVs) of total vehicles in 2030, constant increase of 0.356%/year

30/30 scenario

Electric Vehicles sales percentage scenarios: chosen to reach 30% EV's in 2030, consistent interpolation over 11 years to reach 30% (=3,671,691EVs) of total vehicles in 2030, constant increase of 2.718%/year

EMPLOYMENT CREATION PARAMETERS AND ASSUMPTIONS

Drivetrain, Battery:
- Bottom up study Frauenhofer (Bauer et al., 2018)
  - » Additional to the assumptions the FAO paper makes
  - » Scaling the net direct only (2016) employment factors to 100% of analyzed employment values (p.100, Annex-table) (Bauer et al., 2018)
    - * Including: electric engine, battery production (without cell production), assembly of parts in vehicle, manufacturing of power electronics
    - * See above in the value chain (79%)
  - » 1 production line in shift operation (3 shifts á 8 hours)
  - » EFE * EV sales per year = Final labor demand per year
    - * Ideal conception: linear distribution, but factories don't scale up or down linearly
- Worker:
  - » Direct: Linear increase
  - » Production close Indirect: degressive p.54
  - » Indirect: degressive

Table 10: Scaling the net direct only (2016) employment factors to 100% of analyzed employment values.

Drivetrain analyzed share	Per 250,000 pieces/a	Direct only	Share %	Direct jobs for 100% share
85%	Electric motor	304	100%	358
70%	Battery (without cells)	285	100%	407
55%	Power electronics	74	100%	135
100%	Assembly	89	100%	89
-	-	-	TOTAL	988
-	-	-	Per 1 piece per year	988/250,000 = 0.00395 = EFE

ENERGY SECURITY PARAMETERS AND ASSUMPTIONS

- LHV: gasoline and NAFTA (CONUEE, 2017): 33744.89 MJ/m^3
- LHV/10^9 * yearly Gasoline m^3 = PJ savings per year
- PJ savings per year /Energy consumption in the transport sector in PJ 2015 = Saving in % compared to 2015 level
- All conventional vehicles run on gasoline
- Fuel usage of gasoline vehicles based on the total registered automobiles and motorbikes in 2017 (INEGI)
- Fuel efficiencies adopted from CMM model per vehicle class
- Gasoline vehicle shares adopted from CMM model

ANNEX 5

DRIVING DEVELOPMENT BY INCREASING THE ENERGY EFFICIENCY OF MEXICAN INDUSTRY

DETAILS OF BAU SCENARIOS

The study elaborated by CMM developed a BAU scenario for each industry. CCM built the BAU scenario for iron and steel based on historical data of this industry's energy consumption, except for natural gas, for which SENER's Natural Gas Outlook 2016-2030 was used. The iron and steel industry consumed 162 PJ of energy in 2015 and is expected to consume 189.5 PJ by 2030 (Centro Mario Molina, 2017). For the cement industry's BAU forecast, CMM employed SENER's Energy Sector Outlooks for petcoke, fuel oil and natural gas. For the remaining fuels, it considered the same growth rate as that of cement production. Other sources were SENER's National Energy Assessments. In 2015, this industry consumed 176.7 PJ (Centro Mario Molina, 2017).

To build the BAU scenario, CONUEE used national official forecasts, information from CONUEE's Database for Energy Efficiency Indicators, and a joint forecast developed by CONUEE, ADEME, AFD and Enerdata (CONUEE, 2018). In 2015, the industries for steel and iron, cement, and chemicals consumed 222.3, 176.8 and 96.8 PJ respectively (CONUEE, 2018), and are expected to demand 321.9, 269.1 and 135.6 PJ respectively (CONUEE, 2018).

ASSUMPTIONS AND METHODOLOGY FOR CALCULATIONS

Table 11: Fuel and electricity shares of energy use in the cement industry in Mexico, 2017.

	2017 Energy use (PJ)	Share of total	Fuel	Electricity
Cement	175.341	-	79.05%	20.95%
Coal	7.055	4.02%	5.09%	-
Coal coke	0	0.00%	0.00%	-
Petroleum coke	119.509	68.16%	86.22%	-
LPG	0	0.00%	0.00%	-
Diesel (1)	0.1	0.06%	0.07%	-
Fuel oil	2.209	1.26%	1.59%	-
Dry gas (2)	9.737	5.55%	7.02%	-
Electricity (3)	36.731	20.95%	-	-

Table 12: Fuel and electricity shares of energy use in the iron and steel industry in Mexico, 2017.

	2017 Energy use (PJ)	Share of total	Fuel	Electricity
Iron and steel	248.053671	-	92.00%	8.25%
Coal coke	63.750393	26%	28.01%	-
Petroleum coke	2.941259	1%	1.29%	-
LPG	0.009545	0%	0.00%	-
Diesel (1)	0.743844	0%	0.33%	-
Fuel oil	1.7667	1%	0.78%	-
Dry gas (2)	158.378977	64%	69.59%	-
Electricity (3)	20.462953	8%	-	-

Table 13: Fuel and electricity shares of energy use in the chemical industry in Mexico, 2017.

	2017 Energy use (PJ)	Share of total	Fuel	Electricity
Chemical	-	-	85.6%	14.4%
Coal coke	0.000	0.0%	0.0%	-
Petroleum coke	5.362	4.9%	5.7%	-
LPG	0.774	0.7%	0.8%	-
Diesel (1)	3.863	3.5%	4.1%	-
Fuel oil	2.344	2.1%	2.5%	-
Dry gas (2)	81.382	74.3%	86.8%	-
Electricity (3)	15.798	14.4%	-	-

LIST OF MEASURES INCLUDED IN THE NDC COMPATIBLE AND SD+ SCENARIOS:

Table 14: NDC compatible and SD+ scenario measures.

NDC compatible scenario	SD+ scenario
Cement measures	
Penetration of alternative fuels	Preheater/Precalciner kiln
Grinding improvements	Efficient clinker cooling
Efficient fans for preheating	Use of flyash for clinker substitution
Frequency inverters in motors	Use of slag for clinker substitution
-	Efficient burners
-	Heat recovery
-	Additional stages for preheaters
Iron and Steel measures	
Molding and direct steel forming	Molding and direct steel forming
Thin Slab Casting	Thin Slab Casting
Efficient electric arc furnaces	Efficient electric arc furnaces
-	Highly efficient kilns
Chemical measures	
Steam - Thermal Insulation	Efficient electric motors
Steam - Condensed Handling	Efficient pumping systems
Steam - Combustion Adjustment	Variable speed drives
Steam - Retrieve of Heat Gases of Comb. - Economizer	Efficient compressors
Steam - Recovery of Purge Heat	Efficient lighting
Steam - High Efficiency Burners	Improved steam generation systems
Heaters/Ovens - Retrieve of heat (combustion air)	Improved process control
Heat thermal fluid - Gas - air heat recovery/economizer	Cogeneration
Refrigeration insulation	-
Efficiency in pumping, Compressors and ventilation	-

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