‘Scenario-based sustainability assessment’ of a solar energy transition in Mixteca-Puebla, Mexico

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Abstract

Poverty is a multidimensional phenomenon. It comprises aspects related to living conditions that threaten the dignity of people, limit their exertion of rights and freedoms, prevent the fulfillment of their basic needs and hamper their full social integration. Eradicating poverty is an indispensable requirement for sustainable development. An energy transition which aims at introducing renewable energy technologies in rural areas of low-income regions, where the low affordability of electricity limits the prospects of its population, could offer an opportunity to mitigate poverty.

The provision of solar energy may enhance the prospects of the poor, not only in respect of basic services, but also in new job opportunities, as an additional source of income, improved access to health and education, as well as reduction of climate change impacts. A renewable energy transition brings the opportunity to consider the embeddedness of the energy system in the society, while developing appropriate policy measures to achieve a sustainable future energy system, and thus to make use of the social value of energy. This means that the solar energy system needs to be designed in such a way that it will enable communities to strive for productive uses of social value creation. This would boost communities' capacity of organization and knowledge creation, thus creating positive impacts in their daily lives, with the ultimate goal of enhancing the wellbeing of the population.

This presented research aims to identify conditions that could lead to alleviating poverty in a poverty-ridden rural area in Central Mexico, i.e. Mixteca -in the state of Puebla- through the implementation of a solar energy system. The analysis will consider the interaction of economic, technological, environmental, societal, political and cultural conditions under a sustainability perspective. The focus of this study is to explore the relevance of societal features on the structural energy system transformation in the future trends envisioned for the study area.

To conduct a comprehensive assessment of possible energy futures for the selected region, scenario technique is combined with sustainability assessment, defining joint system boundaries which address the entire regional energy system. The scenarios development makes use of the Cross-Impact Balance (CIB) approach, which allows for a comprehensive presentation of the regional energy system. For the scenario development, insights from the social value of energy approach were used. The sustainability assessment of the scenarios is based on the Integrative Concept of Sustainability (ICoS). Thus, the framework this study introduces is called *Scenario-based Sustainability Assessment.*

The research identified eighteen interrelated factors exerting influence in the solar energy system transformation in Mixteca. Eight scenarios resulting from the CIB are arranged in two divergent clusters to provide an overview of the plausible future in the region, and these also form the base for the sustainability assessment. One cluster shows a rather promising future; the other is rather bleak. The set of scenarios comprising the first cluster would bring better instances for a sustainable future in most aspects. The states of the criteria identified as main drivers and promoters of sustainable development in the region are: *low uncertainties in governance, enforcement of the legal system, excellent cooperation between government, private investors and NGOs, supportive policies on renewable energy systems, good added value creation from the renewable energy sector,* and *low impacts of climate change*. This overall positive assessment shows indications that the future society in Mixteca has learnt to balance the three main goals of ICoS: *Securing existence, Maintaining society's productive potential,* and *Preserving society's options for development and action*. The other set of scenarios, comprising the second cluster, reveal combinations of states of criteria which discourage sustainable development: *strong uncertainties in governance without growth, an aggravated legal system, nonexistent or low cooperation between government, private investors and NGOs, restrictive policies on renewable energy systems, nonexistent (or very low) added value creation from renewable energy, high impact on climate change*. This research also explored the perspectives that would promote the transferability of these findings to other circumstances and regions.

Through this case study, the identification and understanding of societal impacts reveal that they are strong drivers of energy system transformation. Moreover, the societal-related aspects influencing the wellbeing of the communities are more significant than a pure change of the energy system. If the societal impacts are appropriately considered, then the energy system transformation could be the means to uplift conditions such as basic services, health provision, education, employment opportunities creation, and even wealth distribution in Mixteca in the future scenarios. Hence, the social value of energy increases, and poverty alleviation under a sustainable perspective could take place.

Zusammenfassung

Armut ist ein multidimensionales Phänomen. Sie adressiert unterschiedliche Aspekte der Lebensbedingungen, die die Würde der Menschen bedrohen, die die Ausübung von Rechten und Freiheiten einschränken, die die Erfüllung von Grundbedürfnissen beeinträchtigen und ihre soziale Integration behindern. Die Beseitigung von Armut ist daher eine unabdingbare Voraussetzung für eine nachhaltige Entwicklung. Eine Transformation des Energiesystems (oft als Energiewende bezeichnet), welche auf die Einführung von Technologien für erneuerbare Energien in ländlichen Gebieten mit niedrigem Einkommen abzielt, könnte eine Möglichkeit zur Linderung der Armut bieten. Denn gerade hier bedeutet ein geringes Einkommen auch einen erschwerten Zugang zu Energie.

Die Bereitstellung von Solarenergie kann nicht nur die Versorgung mit Wasser und Strom sowie den Zugang zu Gesundheit und Bildung verbessern, sondern auch die Entsorgung von Abwasser, neue Beschäftigungsmöglichkeiten schaffen, zusätzliche Einkommensquellen erschließen, und einen Beitrag zur Verlangsamung des Klimawandels leisten. Die Umstellung auf erneuerbare Energien bietet daher die Möglichkeit, das Energiesystem gesellschaftlich besser zu verankern. Dazu müssen geeignete politische Maßnahmen entwickelt werden, die eine Energiewende ermöglicht und zugleich den sozialen Wert von Energie berücksichtigt. Das bedeutet, dass das Solarenergiesystem so gestaltet werden muss, dass es Gemeinschaften in die Lage versetzt einen gesellschaftlichen Nutzen daraus zu ziehen, bspw. über eine Beteiligung an der Wertschöpfung. Dies würde die Fähigkeit der Gemeinschaften zur Organisation und Schaffung von Wissen fördern und somit auch positive Auswirkungen auf ihr tägliches Leben haben, mit einem Mehrwert für das Wohlbefinden der Bevölkerung.

Die vorliegende Studie zielt darauf ab, die Bedingungen zu identifizieren, die zu einer Verringerung der Armut durch die Einführung eines Solarenergiesystems in einem von Armut geprägten ländlichen Gebiet in Zentralmexiko (in Mixteca im Bundesstaat Puebla) führen würden. Die Analyse berücksichtigt das Zusammenspiel von wirtschaftlichen, technologischen, ökologischen, gesellschaftlichen, politischen und kulturellen Bedingungen unter dem Gesichtspunkt der Nachhaltigkeit. Der Schwerpunkt dieser Studie liegt auf der Untersuchung der Relevanz gesellschaftlicher Merkmale für die Energiewende in dem Untersuchungsgebiet.

Um eine umfassende Bewertung möglicher Energiezukünfte in der ausgewählten Region vorzunehmen, wird die Szenariotechnik mit einer Nachhaltigkeitsbewertung kombiniert, wobei für beide gemeinsame Systemgrenzen auf Basis des gesamten regionalen Energiesystems definiert werden. Die Szenarienentwicklung bedient sich des Ansatzes der Cross-Impact Balance (CIB), der eine umfassende Darstellung des regionalen Energiesystems ermöglicht. Für die Szenarienentwicklung wurden Erkenntnisse des *Social Value of Energy*-Ansatzes genutzt. Die Nachhaltigkeitsbewertung der Szenarien basiert auf dem Integrativen Konzept der Nachhaltigkeit (Integrative Concept of Sustainability (ICoS)). Daher wird der in dieser Studie vorgestellte Ansatz als *Szenariobasierte Nachhaltigkeitsbewertung* bezeichnet.

Im Rahmen der Studie wurden achtzehn Faktoren identifiziert, die in Wechselbeziehung zueinanderstehen und einen Einfluss auf die Transformation des Solarenergiesystems in Mixteca ausüben. Mit Hilfe des CIB-Ansatzes wurden acht Szenarien ermittelt, die zwei unterschiedlichen

Clustern zugeordnet wurden. Die Szenarien geben einen Überblick über plausible Zukünfte in der Region – diese bilden auch die Grundlage für die daran anschließende Nachhaltigkeitsbewertung.

Einer der beiden Cluster zeigt eine eher vielversprechende Zukunft, das andere eine eher düstere. In dem ersten Cluster dominieren Faktoren, die eher eine nachhaltige Zukunft erwarten lassen. Die folgenden Kriterien wurden als Treiber für eine nachhaltige Entwicklung in der Region identifiziert: *adäquate Governance, funktionierendes Rechtssystems, gute Zusammenarbeit zwischen Regierung, privaten Investoren und ZGOs, erneuerbare Energien unterstützende Politik, positive Wertschöpfung des Sektors Erneuerbare Energien, geringe Auswirkungen des Klimawandels*. Diese insgesamt positive Bewertung impliziert, dass die zukünftige Gesellschaft in Mixteca gelernt hat, die drei Hauptziele von ICoS auszubalancieren: *Sicherung der menschlichen Existenz, Erhaltung des gesellschaftlichen Produktivpotentials und Bewahrung der Entwicklungs- und Handlungsmöglichkeiten*.

Das zweite Cluster zeigt eine Kombination von Kriterien, die einer nachhaltigen Entwicklung eher entgegenstehen: *starke Unsicherheiten hinsichtlich des Governance ohne Wirtschaftswachstum, ein nicht funktionierendes Rechtssystem, eine nicht vorhandene oder geringe Zusammenarbeit zwischen Regierung, privaten Investoren und ZGOs, eine restriktive Politik hinsichtlich erneuerbarer Energien, nicht vorhandene (oder sehr geringe) Wertschöpfung des Sektors Erneuerbare Energien, starke Auswirkungen des Klimawandels*.

Weiterhin wurden auch die Möglichkeiten der Übertragbarkeit der Ergebnisse auf andere Gegebenheiten und Regionen untersucht.

Die Fallstudie zeigt, dass die Identifikation und das Verständnis gesellschaftlicher Auswirkungen wichtige Treibkräfte für die Energiewende sind. Darüber hinaus sind die gesellschaftlichen Faktoren, die sich auf das Wohlbefinden der Gemeinschaften auswirken, wichtiger als eine reine Veränderung des Energiesystems. Wenn die möglichen gesellschaftlichen Wirkungen angemessen berücksichtigt werden, könnte die Energiewende ein Mittel zur Verbesserung der Lebensbedingungen (Grundversorgung, Gesundheitsversorgung, Bildung usw.), zur Schaffung von Beschäftigungsmöglichkeiten und sogar zur besseren Verteilung des Wohlstands in Mixteca sein. Somit könnte der soziale Wert der Energie gesteigert und die Armut unter einer nachhaltigen Perspektive gelindert werden.

Resumen

La pobreza es un fenómeno multidimensional. Comprende aspectos relacionados con las condiciones de vida que amenazan la dignidad de las personas, limitan el ejercicio de sus derechos y libertades, impiden la satisfacción de sus necesidades básicas y dificultan su plena integración social. Erradicar la pobreza es un requisito indispensable para el desarrollo sustentable. Una transición energética que tenga como objetivo la introducción de tecnologías de energías renovables en las zonas rurales de países en desarrollo, donde el acceso a la energía eléctrica limita las perspectivas de su población, podría ofrecer una oportunidad para mitigar la pobreza.

El suministro de energía solar podría mejorar las perspectivas de la población en situación de pobreza no sólo en el acceso a los servicios básicos, sino también en nuevas oportunidades de empleo, como fuente adicional de ingresos, mejorar el acceso a la salud, la educación, así como en la reducción de los impactos del cambio climático. La transición a las energías renovables brinda la oportunidad de revalorar la manera en cómo se encuentra integrado el sistema energético en la sociedad, al mismo tiempo que se diseñan normas y disposiciones adecuadas para desarrollar un futuro sistema energético sustentable y, de este modo, aprovechar el valor social de la energía. Esto significa que el sistema de energía solar debe diseñarse de tal manera que permita a las comunidades esforzarse por aspirar a lograr usos productivos de la energía con la capacidad de creación de valor social. Esto incrementaría la habilidad de organización de las comunidades, la producción de conocimiento, logrando así impactos positivos en su vida cotidiana con el objetivo final de mejorar el bienestar de la población.

La presente investigación tiene como objetivo identificar las condiciones que podrían conducir a mitigar la pobreza en una zona rural marginada en el centro de México, en la Mixteca -en el estado de Puebla-, a través de la implementación de un sistema de energía solar. El análisis considera la interacción de las condiciones económicas, tecnológicas, ambientales, sociales, políticas y culturales bajo una perspectiva de sustentabilidad. El enfoque de este estudio es explorar la relevancia de los aspectos sociales en la transformación estructural del sistema energético para los escenarios futuros obtenidos para el área de estudio.

Con el fin de realizar una evaluación integral de los posibles escenarios energéticos futuros de la región seleccionada, se combina la elaboración de escenarios con la evaluación de la sustentabilidad, no obstante, en ambos casos se definen conjuntamente los límites del sistema, que abarcan todo el sistema energético regional. El desarrollo de escenarios utiliza el enfoque del Balance de Impactos Cruzados (Cross-Impact Balance -CIB- por su nombre y siglas en inglés), que permite una presentación integral del sistema energético regional. Para el desarrollo de los escenarios se utilizó el enfoque del valor social de la energía. La evaluación de la sustentabilidad de los escenarios se basa en el Concepto Integrador de la Sustentabilidad (Integrative Concept of Sustainability -ICoS- por su nombre y siglas en inglés). Así, el marco de referencia que introduce este estudio se denomina *Evaluación de la Sustentabilidad basada en Escenarios*.

La investigación identificó dieciocho factores interrelacionados entre sí que ejercen influencia en la transformación del sistema de energía solar en la Mixteca. Ocho escenarios son el resultado del análisis CIB, dispuestos en dos grupos divergentes proporcionan una visión general y factible del futuro en la región, estos son también la base para la evaluación de la sustentabilidad. Un grupo muestra un futuro bastante prometedor; el otro, uno bastante sombrío. El conjunto de escenarios que comprende a uno de los grupos podría aportar mejores instancias para un futuro sustentable en la mayoría de los aspectos. Los estados de los criterios identificados como principales impulsores y promotores del desarrollo sustentable en la región son: *baja incertidumbre en la gobernanza, aplicación del ordenamiento jurídico, excelente cooperación entre el gobierno, los inversionistas privados y las ONG, políticas de apoyo a los sistemas de energías renovables, buena creación de valor añadido del sector de las energías renovables, bajos impactos del cambio climático*. Esta evaluación global positiva muestra indicios de que la sociedad futura de la Mixteca ha aprendido a equilibrar los tres objetivos principales del ICoS: *Asegurar la existencia, Mantener el potencial productivo de la sociedad y Preservar las opciones de desarrollo y acción de la sociedad*. El segundo conjunto de escenarios, revelan una combinación de criterios que desalientan un desarrollo sustentable: *fuertes incertidumbres en la gobernanza sin crecimiento económico, un sistema jurídico deteriorado, una inexistente o baja cooperación entre gobierno, inversionistas privados y ONGs, políticas restrictivas en sistemas de energías renovables, inexistente (o muy baja) creación de valor añadido a partir de energías renovables, alto impacto en el cambio climático*. Esta investigación también exploró las perspectivas que promoverían la transferibilidad de los hallazgos a otras circunstancias y territorios.

A través de este caso de estudio, se demuestra que la identificación y comprensión de los impactos sociales son un fuerte estímulo de la transformación del sistema energético. Además, los aspectos sociales que influyen en el bienestar de las comunidades son más importantes que el cambio del sistema energético. Si los impactos sociales se consideran adecuadamente, la transformación del sistema energético podría ser el medio para mejorar las condiciones de vida como servicios básicos, provisión de salud, educación, la creación de oportunidades de empleo, e incluso la distribución de la riqueza en la Mixteca en escenarios futuros. Por lo tanto, el valor social de la energía aumenta y la mitigación de la pobreza bajo una perspectiva sustentable podría llevarse a cabo.

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Last but not least, to the rural communities in Mixteca, I hope that this research could bridge the gap and transition from theoretical knowledge to practical action (eventually) and serve you in the ways that are most needed: to uplift the wellbeing of the poorest in a sustainable coordinated effort of action.

Overview

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ASOLMEX	Asociación Mexicana de Energía Solar A.C (Mexican solar energy association)
CIB	Cross Impact Balance
CIGS	Copper-indium/gallium-diselenide/sulfide thin film
CIM	Cross Impact Matrix
CO_2	Carbon dioxide
CONEVAL	Consejo Nacional de Evaluación de la Política de Desarrollo Social (Mexican National Council for the Evaluation of Social Development Policy)
CSP	Concentrated Solar Power
DNI	Direct normal irradiance
EJ	Exajoules
EVA	Ethylene vinyl acetate (PV thin films)
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse gas
GW	Gigawatt
ICoS	Integrative Concept of Sustainability
ICT	Information and Communication Technologies
IPL	International Poverty Line
kWh	Kilowatt-hour
kWh/m^2	Kilowatt-hours per square meter
LCOE	Levelized cost of electricity
MW	Megawatt
MxNOM	Mexican Official Standard (Norma Oficial Mexicana)
NH_3	Ammonia (Hydrogen nitride)
NGO(s)	Non-governmental organization(s)
NOx	Nitrogen oxides
NREL	National Renewable Energy Laboratory
PM_{10}	Particulate Matter with diameters 10 micrometers and smaller
$PM_{2.5}$	Particulate Matter with diameters 2.5 micrometers and smaller
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
O&M	Operation and maintenance (cost)
PRODESEN	Programa de Desarrollo del Sistema eléctrico nacional (Mexican electric system development program)
PTC	Parabolic trough collector
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy system
SA	Sustainability assessment
SD	Sustainable development
SDG(s)	Sustainable Development Goal(s)
SENER	Secretaría de Energía (Mexican Ministry of Energy)
SES(s)	Social-ecological system(s)

SO_2	Sulfur dioxide
ST	Solar tower
TWh	Terawatt-hour
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
VOC	Volatile organic compounds
WCED	World Commission on Environment and Development
WHO	World Health Organization
$\mu g/m^3$	Micrograms per cubic meter

"Overcoming poverty is not a gesture of charity, it is an act of justice.
It is the protection of a fundamental human right, the right to dignity and a decent life"

— Nelson Mandela (2005)

1. Introduction

1.1 Motivation

The world is becoming far wealthier but wealth tends to be highly concentrated in a small population group. Inequality keeps growing despite commitments to decrease it. Almost half of the world's population still lives in poverty (World Bank, 2022). Three-quarters of the poorest families live in rural areas (IFAD, 2021) where their future is insecure and vulnerable. The efforts to overcome poverty may be at risk from the unavoidable disruptive effects of climate change. A dual effect and course of action are needed: to strengthen the efforts to fight against poverty while taking a sustainable scope.

Accelerated climate change and its impact on the environment and the population demands a transformation of the energy system towards renewable sources, hence the importance of a defined transition framework, which includes potential threats and possible outcomes. However, the energy transition may frame the change in a way that unintentionally downplays the profound political, cultural, environmental, and above all social disruptions that this energy change conveys. A sustainable energy system transition involves multiple factors other than the technological transformation (Grunwald, 2018).

Literature on sustainable transitions addresses the deployment of specific technologies (Orehounig et al., 2015; Østergaard, 2009), or focuses on financial aspects (Vidal-Amaro et al., 2015) or environmental concerns (Terrapon-Pfaff et al., 2014). Social factors are usually taken as a constant in the analysis (Dewald et al., 2019), and the complex multidisciplinary processes that may sustain or hinder social features (Miller et al., 2013) are rarely analyzed. Thus, there is a need to explore energy transition processes through the shifts between the dynamics of networks, communities, and governance contexts in which the different types of actors interact (Geels, 2004).

While the concept of 'energy transition' has a connotation related to security, efficiency and sustainability among the high-income economies (Bartiaux et al., 2019; Pastukhova and Westphal, 2020), in low-income countries the 'energy transition' deals with the dilemma of gaining affordable access to energy services, without becoming trapped in a fossil fuels-intensive future (Bradshaw, 2010). The low-income economies face the challenge of sustainable development to promote energy justice and equity, economic development and poverty alleviation, whilst contributing to curbing climate change (Hulme, 2015). A renewable energy transition in rural areas of low-income countries, where the unaffordability of electricity results in limited energy availability to its population, could offer an opportunity to mitigate poverty. As this research suggests, in addition to improving basic services, the provision of solar energy may also provide job opportunities, an additional source of income, value added to renewable energy sources, reduction of climate change impacts, and above all, poverty alleviation.

Extensive research has established and measured energy transition successes through the choice and promotion of a specific technology (Bartiaux et al., 2019; Bradshaw, 2010; Brosemer et al., 2020; Burke and Stephens, 2018; Creţan and Vesalon, 2017; Criqui and Mima, 2012; Geels, 2014; Orehounig et al., 2015; Østergaard, 2009; Vãran and Creţan, 2018; Vidal-Amaro et al., 2015). However, the integration of societal needs has not been sufficiently considered (Practical Action, 2014). Research on energy transition in low-income economies has been mainly focused on choosing the appropriate (renewable) energy technology and its expansion, aiming mostly to tackle energy poverty (IEA, 2017). However, when discussing low-income economies, access to energy does not necessarily alleviate income poverty or any other dimensions of poverty (Singh and Chudasama, 2020; United Nations, 2020). Hence, identifying context-specific factors critical to the success of poverty alleviation research is vital. Sovacool recognizes that when the energy technology system considers the societal context, renewable energy systems can be effective (Sovacool, 2013). Recent research suggests that the energy transition should not be seen as a transfer of technologies, but rather as a transformation of the entire system (Ulsrud et al., 2015). Miller calls a system that delivers social value (Miller et al., 2015b) and incorporates the social dynamics of diverse communities into its design, a socio-energy system (Miller et al., 2015a).

Since there is a tight bond between poverty and energy poverty, which is exacerbated in low-income countries (Nadimi and Tokimatsu, 2018), when adding a sustainability component to analyses, scholars focus on the contribution of renewable energy (Ghasemian et al., 2020; Midilli et al., 2006). Thus, the initial approach of the sustainability concept is steered from the perspective of environmental protection and its impacts on the population (Dincer, 2000), and the discussion remains open as to other societal influences, without a deep understanding of the interconnections between them (Reddy et al., 2006).

Strategies have been designed with the aim to reduce poverty through energy access (Abbas et al., 2021; Khan and Arefin, 2013). However, the drawback of these programs is that while they tackle the specific dimension of poverty the program has been designed for, they do not reflect on any of its cultural or social aspects (World-Bank, 2008). Moreover, there is no conclusive evidence regarding an improvement in other dimensions of poverty, such as health, education or livelihood (Montgomery and Weiss, 2011). Nor do these strategies provide evidence of how sustainable the measures are, or if the solution could be part of a sustainable future.

The transition from fossil fuels systems is embedded under this existing landscape where poverty and energy converge. Energy transition needs an understanding of social aspects and vulnerabilities. A renewable energy transition brings the opportunity to re-think the system and re-focus on sustainability, wealth distribution, justice, improvement of wellbeing, and climate change cooperation. A need to identify risks, challenges, priorities and drivers of change are considered under the societal scope. Many basic factors will be mutually connected. With this new overview, a gap emerges in the understanding of the interplay between societal aspects, sustainability and energy transition in how to improve the living conditions of impoverished communities. These perceptions will help us understand whether an energy transition could uplift the wellbeing of the poorest sector of the population or not, and under what conditions.

1.2 Aim of the dissertation

This dissertation seeks to contribute to the research gap between energy system transformation and the societal features immersed in it, under a systematic framework of sustainability, with the objective of poverty alleviation. The focus of this study is to explore the impact of societal features on the structural energy system transformation, and its capacity for adaptation in the future trends envisioned for a designated area.

Despite the importance of societal needs, a thorough understanding of how to integrate these into a sustainable technological transformation is still necessary (Burke and Stephens, 2018). Literature is scarce, particularly with regard to the emerging role of the paradigm shift, in which technology is not the end of the transformation (Börjeson et al., 2006) but the means of the transition. This research attempts to contribute in this respect, by taking the case of rural Mixteca in Mexico to understand a technology transformation as the means to improve living conditions and pursue the alleviation of poverty towards a sustainable future, considering the social value of energy (Miller et al., 2018). This dissertation explores the possibility of taking advantage of the energy transition to contribute to economic and social development in impoverished regions.

Mixteca is identified as a largely neglected region within the state of Puebla, in central Mexico. It covers an area around one-third of Puebla state's territory; due to its geographic location and climatic conditions - arid, dry and hot - productive activities are scarce, hence, it is a poverty-ridden region (Gobierno de Puebla, 2011). Nevertheless, the region is rich in high solar radiation which remains untapped. The outstanding solar resources could make the region a valuable contributor of renewable energy. Focusing the transition on the social value of energy could bring an uplift of wellbeing to the population and a model worthy of replication in other regions.

This research aims to alleviate poverty in Mixteca through the implementation of a solar energy system considering the interaction of economic, technological, environmental, societal, political and cultural impacts in the rural region. This solar energy system could trigger the energy transition by re-designing the societal landscape into one in which the social value of energy can be both at the core of, and the means to, poverty alleviation.

1.3 Research questions and approach

Tackling the gap mentioned, and adopting a renewable energy transition as a framework for systematic societal change to alleviate poverty under a sustainable perspective is addressed by the following research questions:

1. What are the socio-economic factors which could promote a sustainable performance in Mixteca by transitioning to solar energy technology?
2. What could a sustainable future look like, and how could Mixteca achieve it?
3. Is there a sustainable future that could promote poverty alleviation in the region?
4. How to develop a consistent framework to conduct a comprehensive scenario assessment?

These questions are relevant because the region has endured poverty for the last centuries; a lack of understanding about societal needs has brought temporary solutions and dependence on external income, and a lack of human capital development has persisted, while solar resources have remained untapped. Mixteca calls for a change, beyond modern life and technology, and a transition into a solar energy system motivated by (positive) societal impacts.

The research study intends to identify the criteria and conditions under which a solar sustainable energy system could be implemented in Mixteca to improve wellbeing, as well as to determine which factors could promote or impede the transition. By exploring the complexities of societal conditions, the research shall contribute sustainable perspectives to increase living standards and reduce poverty in the rural area. The result of the socio-economic, political, technological, cultural and societal interrelationships of the criteria shall facilitate plausible future scenario trends on the base of a sustainability assessment. The projection of outcomes should contribute to insights to transfer the results of this model to other regions. This research is also useful to identify the perspectives that would promote such transferability.

The main scientific challenge of the research is to develop a consistent and transferable framework that can both comprehensively and systematically identify and assess the sustainability of future scenarios. To meet this challenge, the integration of two established approaches is proposed, using a framework that this study calls *Scenario-based sustainability assessment*: the Cross-Impact Balance (CIB) and the Integrative Concept of Sustainability (ICoS). Additionally, the societal scope is addressed with the support of the social value of energy framework.

The Cross-Impact Balance (Weimer-Jehle, 2006) approach will be used to describe and analyze the main elements that promote but also impede a future energy system transformation. To identify sustainable combinations of the energy system, the Integrative Concept of Sustainability (ICoS) (Kopfmüller et al., 2001) will be applied. The social value of energy (Miller et al., 2018) is a useful approach to shift the conventional technologically- centered argumentation into a perspective that recognizes that the design of energy systems is a consequence of the social interrelationships within the system.

The integration of the CIB and ICoS approaches intends to fill the scientific research gap, where CIB provides scenario analyses regardless of the sustainability dimension, while ICoS needs the support of a structured methodological design. The consideration of the societal values shapes - positively as well as negatively - the technological transition, and is thus essential to its integration.

The Cross-Impact Balance analysis is designed to assist in building qualitative scenarios based on expert judgments on the relevance and interdependence of scenario components, and the Integrative Concept of Sustainability deals mostly with qualitative information, the combination of both methods intends to bring the best insights for implementing a solar energy system. Considering social and sustainable factors and not only technological and economic aspects, will benefit stakeholders and the social community in Mixteca, thus providing an increase in living standards and reducing poverty in the rural area.

1.4 Outline of the dissertation

This dissertation is divided into five parts:

Part 1	Background, research scope, objectives	Chapter 1	Introduction: motivation, aim, research questions, outline
Part 2	Framework on methodology, case study and technology	Chapter 2 Chapter 3 Chapter 4	Approach and methodology: state of the art Rural Mixteca: status quo Solar energy system overview
Part 3	Theoretical approach (method)	Chapter 5	Introducing 'Scenario-based Sustainability Assessment'
Part 4	Application of the method	Chapter 6 Chapter 7	Constituents and attributes Adaptation to local conditions
	Results	Chapter 8 Chapter 9	Scenario results presentation Sustainability assessment results presentation
Part 5	Transferability, considerations, conclusions, outlook	Chapter 10 Chapter 11	Transferability of the findings Paving the path to a better future

The detailed structure of the dissertation is presented as follows:

Part 2:

Chapter 2 offers a review of literature in three main aspects: social value of energy (section 2.1), sustainability assessment (section 2.2), and scenario analysis (section 2.3). Concepts of the social value of energy, poverty, sustainability assessment and scenario analysis are explored. In particular, Chapter 2 supports highlighting the view of the energy transition through the social lens.

Chapter 3 provides a general overview of the spatial, socio-economic, political, geographical and cultural context of the rural Mixteca in Puebla, Mexico. These particular framework conditions are required to understand the current situation in the area and provide the context and boundaries for the research. This chapter deepens key aspects in order to understand what poverty looks like in the region, level of community participation, provision of income, employment, education, in order to understand the multifaceted and interrelated contexts in which society in Mixteca evolves.

Chapter 4 offers a review of the two most important solar energy technologies for generating electricity from the sun's radiation: concentrating solar power (section 4.1) and photovoltaic systems (section 4.2). The chapter provides an analysis of the solar technology status in the region (section 4.3). A cost analysis for Mixteca is provided to evaluate economic feasibility to install either technology alternative (section 4.4). The chapter offers a critical analysis of the benefits and drawbacks of each of the technologies applied to the circumstances in Mixteca. It concludes with a proposal of the most suitable technology for the area considering the geographic conditions and the socio-economic circumstances: the solar PV system (section 4.5).

Part 3:

Chapter 5 outlines the methodology used throughout this study, *Scenario-based sustainability assessment,* which proposes the integration of two existing approaches: the Integrative Concept of Sustainability (ICoS), and Cross-Impact Balance (CIB), with the aim to provide a normative system for a comprehensive sustainability assessment of plausible future scenarios. The chapter discusses each of the two approaches.

The ICoS concept includes three goals of sustainable development focused on a global perspective, a justice assumption and an anthropocentric approach (section 5.1). Fifteen substantial rules identify the minimum conditions for sustainable development. The instrumental rules which provide the framework conditions to achieve the main goals of sustainability are introduced.

Section 5.2 presents the second step approach, the CIB analysis. CIB was used in this study to analyze the influence of the interdependencies of the future energy system factors by providing an array of possible scenarios and development pathways. This integrates the analysis of the complex interactions between the political, economic, technological and social correspondent factors of the energy system.

Section 5.3 provides the proposed integration of both approaches as the methodology used throughout this study, and the answer to the fourth research question: "How to develop a consistent framework to conduct a comprehensive scenario assessment?". This integration is reached through the contextualization of the system, by providing the framework conditions (descriptors / criteria) as the mutual and pivotal boundaries.

Part 4:

Chapter 6 exhibits the eighteen descriptors / criteria identified for the study case in Mixteca as the boundaries for the *Scenario-based sustainability assessment*. These factors are the constituents of the framework and drivers of the solar PV transition. In addition to their characterization, this chapter presents their future states. The selected time frame for the scenario analysis is 30 years from now, more precisely by 2050, given that a solar PV transition is a long-term process that should be planned with anticipation. The definition, selection and characterization of these 18 descriptors / criteria helped to answer the first research question: "What are the socio-economic factors which could promote a sustainable performance in Mixteca by transitioning to solar energy technology?".

Chapter 7 examines the adaptation of the ICoS sustainability rules to Mixteca's regional conditions. The objective is to tailor sustainability proposals to the local context. Thirteen rules were contextualized through the three goals of the substantial rules (sections 7.1, 7.2 and 7.3). Particular challenges and considerations for this process were analyzed, and conditions such as survival and basic needs provision were identified as top priorities. These might pose a threat to and / or compete with practices for a sustainable future. As a result, indicators to measure progress on sustainability were identified, as well as their targets (section 7.4). The final section (7.5) provides the contextualization of the ICoS instrumental rules.

Chapter 8 presents the results of the scenario analysis, starting with the identification of the active and passive descriptors (driving forces). An analysis of these drivers is provided to understand the degree of influence these exert on the energy transition, with the aim to alleviate poverty (section 8.1). The next section (8.2) presents eight scenarios resulting from the CIB algorithm, as well as the two Clusters in which the scenarios have been arranged. Sections 8.3 and 8.4 scrutinize the two divergent storylines which result from the analysis of interdependences in order to understand the conditions that hinder and / or support the energy transition. Section 8.5 exhibits a comparative summary. The chapter ends with a discussion where the concepts of transformability and basins of attraction (attributes of a social-ecological system) are used to explain changes among the identified scenarios and their pathways to the future.

Chapter 9 provides the outcomes of the *Scenario-based sustainability assessment*. Section 9.1 explores the process of articulating the scenario analysis into the sustainability assessment, where a relative index with a designed scale-up factor was used, along with a traffic light scheme, as a tool to visualize the results. Sections 9.2, 9.3 and 9.4 present the sustainability assessment of each of the three main goals of ICoS, where eighteen criteria were assessed under the pertaining substantial rules. Section 9.5 exhibits a summary of the assessment of the main goals, where the depiction of the arrangement of the scenarios can be observed, as well as their differentiation into two Clusters from the scenario analysis. Section 9.6 provides a sensitivity analysis which validates the robustness of the assessment results. Section 9.7 reveals the results of the sustainability assessment for the instrumental rules, where the same procedure was used as for the substantial rules. The chapter ends with a summary of the assessment of the ICoS instrumental rules (section 9.8) where scenarios 1, 2, 3 and 5 show a lesser degree of sustainability, while scenarios 4, 6, 7 and 8 show the highest degree. This chapter also holds the answer to the second research question: “What could a sustainable future look like, and how could Mixteca achieve it?”. The first half of the question is re-explored in the assessment of the substantial rules (section 9.5), while the second half is addressed through the assessment of the instrumental rules (section 9.8). The third research question: “Is there a sustainable future that could promote poverty alleviation in the region?” is also answered in this chapter (section 9.5).

Part 5:

Chapter 10 identifies the different perspectives under which a transferability of the findings could be attained: the method, the framing, the interconnections, the general outcomes, the specific insights and data, the application and the practical knowledge. The core is related to the proposed method used throughout this study, *Scenario-based sustainability assessment*, whose comprehensive and systematic approach would allow its adaptation to different contexts and circumstances.

Chapter 11 provides a reflection on the challenges of adopting the sustainable approach in the local context of Mixteca (section 11.1), where societal aspects are highlighted as encouraging or restricting a solar PV transition impacting the development of the area. Section 11.2 provides a concluding discussion on three main themes: societal aspects and governance; *Scenario-based sustainability assessment* as a theoretical framework; and the specific application of the framework in Mixteca. Finally, this dissertation concludes with ideas for future research (section 11.3).

"Economic growth without investment in human development is unsustainable - and unethical"

— Amartya Kumar Sen (2016)

2. Approach and methodology: state of the art

This chapter explores the background elements that underpin this study, including an examination of the main concepts and the state-of-the-art. This chapter is divided into three sections. Section 2.1 offers the perspective under which this dissertation was framed: the social aspect. To do so, concepts of poverty and the social value of energy are unpacked to highlight their potential to impact on an energy transition. Section 2.2 offers an overview of the first part of the approach taken in this study: the sustainability assessment. The importance of the impacts of current human actions in the future is addressed through sustainable development, for which several approaches and indicators have emerged. Section 2.3 explores scenario analysis as the second part of the approach employed in this study; its purpose, techniques and uses are presented to understand its benefits. In particular, this chapter outlines the two approaches (ICoS and CIB) used throughout this study for a proposed energy transition through the social lens. Separate chapters are devoted to the Mixteca region under study (chapter 0) and the energy system (chapter 0), providing the detailed analyses required to develop the study. This chapter 2 along with chapters 3 and 4 conform Part 2 of this dissertation: the case study presentation (see chapter 1).

2.1 The social value of energy

2.1.1 Multidimensional poverty

The most urgent task in all of the interconnected challenges of sustainable development is the fight against extreme poverty, because it is a matter of life and death and a struggle for survival in the here and now (Sachs, 2015). Eradicating poverty is an indispensable requirement for sustainable development. Despite commitments, efforts and some progress over the past decades, the world is not on track to ending poverty in all its forms, which is the core objective of the sustainable development goal (SDG) number 1. The World Bank estimated (pre-COVID-19 pandemic), that 9.2 % of the global population still lived below the international poverty line (IPL) of US$1.90 per person per day, which represents the typical poverty line of some of the poorest economies in the world. This percentage amounts to 689 million extremely poor people (World Bank, 2020). The effects of the COVID-19 pandemic, as well as conflict and climate change, highlight the need for a continued focus on addressing extreme poverty.

The definition of poverty is complex, as is its measurement. Poverty has been traditionally linked to inequality in income distribution and, in particular, with the population groups with the lowest participation in this distribution. However, the conceptual boundaries of poverty have expanded to go beyond income to a multidimensional concept. From this perspective, poverty appears to be linked to the living conditions of the population, and becomes a complex, dynamic and relational phenomenon (Laparra et al., 2021).

The United Nations (UN) has broadened the concept of poverty in a multidimensional measure to include a wider set of basic needs beyond lack of income. Poverty has various manifestations, such as productive resources sufficient to ensure sustainable livelihoods, hunger and malnutrition, poor health, limited or lack of access to education and other basic services, increased morbidity and mortality from illness, homelessness and inadequate housing, unsafe environments, social discrimination and exclusion. It is also characterized by a lack of participation in decision-making and in civil, social, and cultural life. The UN stressed that poverty occurs in all countries as a result of economic recession, sudden poverty as a result of disaster or conflict, the poverty of low-wage workers, and the utter destitution of people who fall outside family support systems, social institutions, and safety nets. It was noted that certain social groups are especially vulnerable to poverty, i.e., women, children, the elderly, people with disabilities, indigenous groups, and refugees (UNDP, 2010).

In the Copenhagen Declaration on social development, the UN also identified three core issues that enable the building of secure, just, free and harmonious societies which offer opportunities and higher standards of living for all: poverty eradication, employment generation and social integration (United Nations, 1995). The multidimensional Poverty Index (MPI), calculated by the UN (UNDP, 2010) aims to capture aggregate deprivations in health, education and standard of living, especially due to the high likelihood that households can face constraints on health, education, and standard of living, which are the same dimensions included in the Human Development Index (HDI).

The methodology used by the National Council for the Evaluation of Social Development Policy in Mexico (CONEVAL, Consejo Nacional de Evaluación de la Política de Desarrollo Social) links two distinct perspectives in a single coherent conceptual framework: economic wellbeing and social rights. This identifies the poor as the population lacking both sufficient economic resources and basic access to social rights (such as access to food, health, education, social security or dignified housing) (CONEVAL, 2019). On the basis of this methodology it is possible to adopt a path of comprehensive social development using a rights-based approach, monitor the different dimensions that impact human development, and guide the design of public policies which aim for full social inclusion for everyone.

CONEVAL establishes guidelines and criteria to define, identify and measure poverty, considering the following indicators: income, education lag, access to health services, access to social security, access to food, housing quality and space, access to basic housing services, and degree of social cohesion (CONEVAL, 2018b). Given that these dimensions have a direct impact on the social development of the population, eliminating poverty requires multiple public actions resulting in well-paid jobs with basic benefits, such as protection against accidents or illnesses; school attendance of children and adolescents, and universal coverage of basic education; access to healthcare; minimum housing conditions, as well as adequate food, in quantity, quality and variety.

According to CONEVAL, the multidimensional poor are those who are deprived in at least one of the social dimensions and whose income falls below the wellbeing threshold (LBE, Línea de Bienestar Económico, in Spanish), calculated as the income needed to afford basic food and non-food baskets of goods and services. Within this group, identifying the population living in extreme poverty is of particular relevance. This is defined as having simultaneously an income below the cost of the basic food basket (minimum wellbeing threshold) and three or more social deprivations. These represent the poorest of the poor, who must be prioritized by state policies, given their greater needs and precarious conditions. The moderately poor are those who are poor but not 'extremely poor', according to (CONEVAL, 2019).

For this study and based on the above concepts, the following definition of poverty is used: Poverty is a multidimensional phenomenon which comprises aspects related to living conditions that threaten the dignity of people, limit their rights and freedoms, prevent the fulfillment of their basic needs and hamper their full social integration.

Attempts to alleviate the poverty dimensions while designing a sustainable future for the planet have emerged; the UN recorded multiple work throughout a couple of decades involving proposals such as Agenda 21, a plan of action in a global partnership to improve human lives and protect the environment (United Nations, 1992); the Millennium Development Goals to reduce extreme poverty (United Nations, 2001); the Johannesburg Declaration on sustainable development (United Nations, 2002); the Rio +20 Conference on sustainable development (United Nations, 2012). The quests culminated in the adoption of the 17 Sustainable Development Goals (SDGs) as an urgent call for action by all countries in a shared effort to integrate solutions to make development more sustainable (United Nations, 2015). These goals contain not only social inclusion, but added environmental protection and economic growth as the core objectives of sustainable development.

Through the dedicated goal on energy, SDG 7, the UN call to *ensure access to affordable, reliable, sustainable and modern energy for all* recognizes that "energy lies at the heart of both the 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change" (United Nations, 2018), as energy is crucial for achieving - directly or indirectly - other SDGs due to its role in the eradication of poverty through advancements in health, education, water supply and industrialization, and combat climate change. Moreover, recent research has shown that the interactions between the energy SDG targets and those of the non-energy-focused targets unfold in different degrees depending on their context; a deeply-woven interplay connects energy with the rest of the SDGs, becoming a positive outcome and a good starting point for actors across sectors to raise the likelihood of achieving positive social value of energy (McCollum et al., 2018; Miller et al., 2022).

2.1.2 Energy poverty

There is often a two-way relationship between the lack of access to adequate and affordable energy services and poverty. The relationship is, in many aspects, a vicious cycle in which people who lack access to cleaner and affordable energy are often trapped in a reinforcing cycle of deprivation, lower incomes and the means to improve their living conditions, while at the same time using significant amounts of their very limited income on expensive and unhealthy forms of energy that provide poor and / or unsafe services. Access to cleaner and affordable energy options is essential to improve the livelihoods of the poor in low-income countries. The link between energy and poverty is demonstrated by the fact that the poor in low-income countries constitute the majority of an estimated 2.6 billion people who rely on traditional biomass for cooking, and the overwhelming majority of the 759 million without access to grid electricity. In all sub-regions of the low-income countries, people in rural areas account for the highest proportion of the population relying on traditional biomass, a key indication that rural areas in most low-income countries have limited access to (cleaner) energy (GEA, 2012; United Nations, 2022).

Defining energy poverty is not only a challenging task but a complex and controversial one, mainly due to the context-specifics of the environments where energy is needed. The main discrepancy in the understanding of energy poverty is between high- and low-income countries. European and Western countries relate energy poverty mainly to household needs for heating and cooling, as well as the source of fuel: “Energy poverty occurs when a household is unable to secure a level and quality of domestic energy services—space cooling and heating, cooking, appliances, information technology—sufficient for its social and material needs….it focuses not on issues of fuel affordability, but rather explores which factors determine the quality and type of energy services received in the home” (Bouzarovski, 2018).

On the contrary, low-income countries focus primarily on gaining access to (any) source of energy to satisfy primarily basic demands such as cooking and lighting. Hence, energy poverty is understood as the deprivation of energy services linked to satisfying basic human needs. The Latin American region has a high average rate of access to electricity (98.3%), but this figure disguises an uneven pattern of access with an irregular connectivity rate; moreover, it overlooks issues around quality of supply and affordability. Data from the (World Bank Enterprise Surveys, 2022) shows that 64.8% of businesses in Latin America experienced electrical outages, with an average of 2.1 outages in a typical month, each lasting 2.7 h on average. This is despite the fact that many regions of Latin America are rich in energy resources. Hence, energy poverty is a complex, culturally sensitive and multidimensional concept.

Lifting people from energy poverty is a critical component of ending the poverty trap that consigns hundreds of millions of poor people to lives of hard low-paid work and subsistence work (Practical Action, 2014). The impact on poor communities lies beyond uplifting their basic living standards, but also to enable them to earn a living with education, health and cultural opportunities. From the essential energy services needed at the household level, lighting and cooking are well-recognized, but heating, cooling, and access to communications technologies are factors with transformational effects on the population that are only possible when energy is available and reliable. Uplifting the household level could be the start of the path to poverty alleviation.

For the 689 million of the world’s poorest people (World Bank, 2020), the ability to earn a living depends on access to energy. Having lighting after dark to keep a shop open longer, or fuel for an engine to mill grain or a pump to irrigate land, can be the difference between earning a decent livelihood and remaining at or below the subsistence level and in poverty. It is this direct connection between energy and poverty reduction that is most cited in the discussion over energy poverty, but is least well understood in practice (Abbas et al., 2021; González-Eguino, 2015). The vast majority of poor people work in the informal sector, generating incomes from often a multitude of poorly or unpaid, insecure and physically demanding work. However, revenues generated in the informal sector are not generally included in national statistics or gross domestic product (GDP). The very poor are not unemployed; they work very hard and long hours in unremunerative, unproductive forms of activity, in unskilled or low-skilled labor in formal or informal sectors: Street traders, garbage collectors and casual workers, as well as many in small-scale production such as carpenters, shoemakers, construction workers, and art and craft-makers. These people often work extremely hard, are self-employed or employed by their family, and are very poor. Attention has also been directed to the women who perform hard tasks without being counted as members of the labor force because their production is not sold for cash. Streeten defined this sector as the "working poor" (Streeten et al., 1981).

Energy Poor People report analyzed in detail the multiple benefits energy access could bring in low-income countries to increase the country's wellbeing and economic development, from manufacturing perspectives to self-employment, through to education and community services. From the economic point of view, agriculture is one significant contributor to transform people's earnings, improve productivity, create employment and strengthen the industrial sector. However, energy access has also some drawbacks, such as labor displacement due to automation; lack of skills or training could also exclude those who have not had access to education, or computer-related skills. Crucial benefits rely on community services, which hold the capacity to improve the lives of people in poor regions: health care services benefit from improved refrigeration for vaccines that could prevent diseases; schools and training centers could improve capacity-building including vocational training skills, such as computer literacy, welding, or carpentry. Public institutions such as libraries, police stations, community centers, and infrastructure services could see an improvement in facilities such as street lighting, waste disposal, public transport and sanitation. Energy access has the capacity to enable better lives and livelihoods, thus alleviating poverty (Practical Action, 2014).

2.1.3 The energy poverty nexus and the social value of energy

Nexus framing considers key issues of diverse interrelated sectors, e.g., water-energy-food, through a sustainability view in order to identify potential future risks; the approach also tries to optimize synergies, and identify trade-offs across the sectors involved within its interlinkages, encompassing a holistic concept. This complex, intersecting, interdependent and multi-dimensional relationship is characterized as 'nexus' (Albrecht et al., 2018; Biggs et al., 2015). As energy systems and poverty are very much interconnected, the multi-dimensional interaction between an energy system intersecting the diverse disciplines related to social deprivation, injustice and inequality through the multiple stakeholders is considered the energy-poverty nexus (Alhassan, 2018; Miller et al., 2018). The transformation to renewable energy sources provides a suitable occasion to address global poverty, and thus to contribute to the UN main aim (SDG 1): "end poverty in all its forms everywhere" through the interrelationship of SDG 7: "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2022), while also supporting other sectors involved in the nexus such as basic services like water or sanitation, enabling local development and resilience to climate change.

As Sovacool has pointed out, the production, distribution and consumption of energy is determined by the interactions between the technical and human components of an energy system; the energy system is the result of the actions of individuals, stakeholders and researchers who through an interdisciplinary forum discuss how social and technical issues related to both energy production and consumption interact (Sovacool, 2014). Energy production, distribution, and consumption all have both technical and human components, and the latter involve the human causes and consequences of energy-related activities and processes, as well as social structures that shape how people engage with energy systems. Energy analysis therefore needs to look beyond the dimensions of technology and economics to include these social and human elements in a special cross-cultural and interdisciplinary interaction.

Energy consumption and economic development are linked, and countries whose GDP and human development indexes are higher, show a greater energy consumption than those with lower indexes, i.e. low-income countries (Alhassan, 2018; González-Eguino, 2015). Additional research has evidenced that an increase in income inequality causes higher energy poverty

(Nguyen and Nasir, 2021). Miller points out that it is this gap between social and economic practices that users would need to be concerned about in order to translate the access to energy into an economically productive and at the same time socially valuable development (Miller et al., 2015a). This social component is the proposed centerpiece in the framework of energy policies in which interconnected and integrated systems link social, economic and political dynamics with the design and operation of technological systems. These societal considerations should be more effectively integrated into energy analyses and decision-making.

The objective in this socio-energy approach is to shift the conventional technological-centered argumentation into a perspective that recognizes that the design of energy systems is a consequence of the social interrelationships within the system. The connections in socio-energy systems flow through societal dynamics; the socio-energy systems shape and are shaped by the social, cultural, political and ecological contexts in which they are embedded. At the same time, societal organizations are complex entities whose users' and adopters' behaviors require detailed analysis. This shift to human-centered thinking is "the social value of energy" (Miller et al., 2018). This concept takes into consideration economic and non-economic benefits, i.e., an integral wellbeing as a result of the improvement of related factors such as health, education, basic services provision; it also considers burdens, risks and other negative externalities associated with the generation, transmission or consumption of energy services. See Figure 1 for a depiction of this interrelationship of multiple societal factors. The social value of energy provides a causal link between the influence of energy and the potential for collective wellbeing improvement, impacting at the same time the SDGs. Thus, increasing the social value of energy is critical for reducing multidimensional poverty.

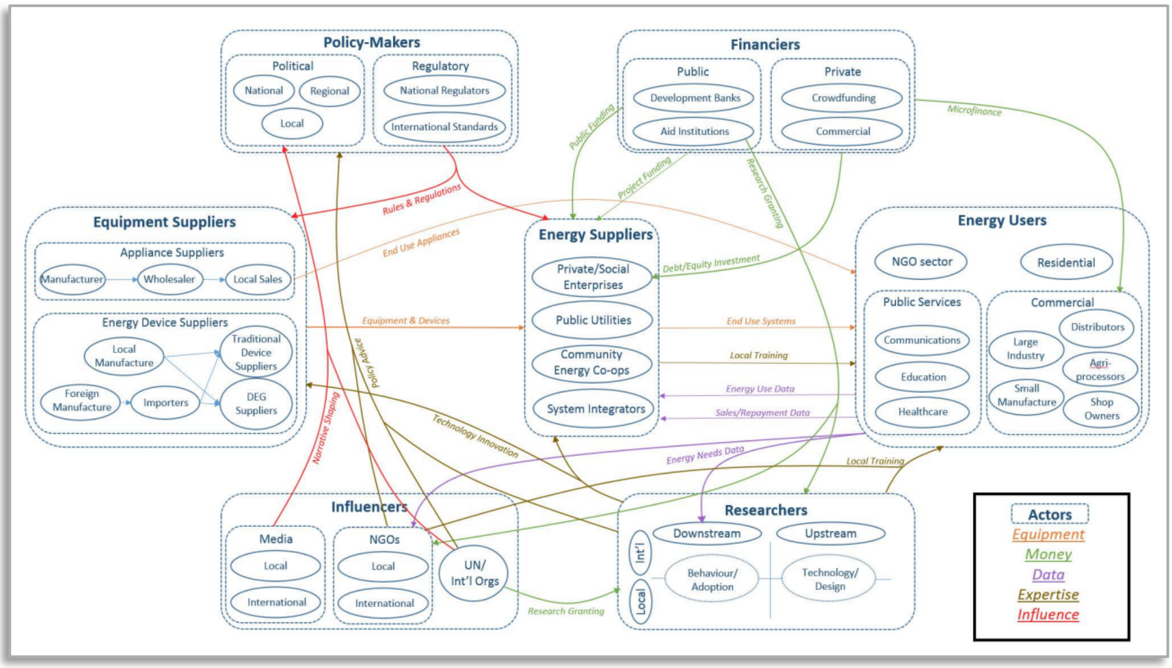


Figure 1. Multi-layer framework for energy access innovation ecosystem for social value creation. Source: (Miller et al., 2018)

Understanding of the social outcomes flowing from energy transitions should aim to be meaningful in terms of justice and equality, as pointed out by Miller; access to energy is the immediate result, but the most influential factor in a community is how the energy is used to enhance the quality of life of its population (Miller et al., 2015a). The arrangement of social and energy systems - socio-energy systems (Miller and Richter, 2014) - is not only important in terms of availability, but also in terms of efficient utilization. Therefore, an energy transition should aim to ensure that social needs are met through the provision of (renewable) energy. Social considerations are essential for creating sustainable communities where the energy transition provides the platform and the opportunity to improve living conditions. The social value of energy is reliant on the capacity of people, households, and communities to transform bare energy access to generate productive uses of energy that can bring about a positive transformation, which includes expertise, skills, and coordination. Special attention should be paid to both non-economic and economic benefits when accounting for the social value of energy, as well as for risks, burdens and other negative externalities. Consequently, as the social value of energy increases, the energy-poverty nexus ends (Miller et al., 2015b; Biswas et al., 2022a) and multidimensional poverty decreases. Mapping and evaluating the existing social value of energy within individual daily life interactions is useful to identify energy services (such as those shown in Figure 1) that will be accounted for and compared to a potential alternative new system. These social-energy relations are also useful to anticipate improvements and enhance social value creation, either through the current system or through a new one as a result of an energy transition. The effective integration of both social and technological factors through a human-centered strategy provides the social value of energy.

Work needs to be undertaken in order to link the concept and the operationalization of the social value approach. Policy frameworks should be designed, technology adapted to enhance social value, and governance arrangements should be supporting the social value approach and planning for a sustainable future to create high levels of social value (Miller and Richter, 2014). The introduction of local community organizations has the potential to be more effectively engaged with their local surroundings, hence, user-centered; for this reason, they could be more successful in addressing issues, problems and challenges. A deeper impact and wealth distribution could be reached if these organizations have the potential to be locally owned, and added value creation - social and economic - would uplift living conditions in the region (Miller et al., 2018; Biswas et al., 2022a). Derived therefrom, bottom-up approaches can be useful to articulate an energy system based on the human-centered perspective of the social value of energy (Biswas et al., 2021b). Then, co-production of knowledge and action promoting the participation of academic and non-academic communities aimed at creating sustainable development pathways in a legitimate and trust-based relationship could be designed. The configuration of the new energy system should consider the engagement of users, for active involvement to improve practices to make the energy system inclusive, self-reflexive and participatory, for the community's wellbeing (Miller et al., 2015b; Biswas et al., 2022a). The production of locally-grounded and actionable knowledge is the central aim of this social-value system; empowering the energy users to design and manage the provision of the social value of energy for socio-economic development should become the basis of energy transitions for a sustainable future (Miller et al., 2013).

Successful examples of local communities using bottom-up design have challenged financial models, contributing added value to the area; these instances have permeated through vulnerable communities, generating community coordination. These communities have taken an independent lead towards development, designing autonomy into their energy decentralization strategies and the transition to a sustainable future (Biswas et al., 2021a). In their research, Shahid et al. (2021) have gone one step further and have drawn the attention of policymakers to consider energy as a contributory factor in human development, and propose to incorporate it as a parameter in calculating the human development index.

Additional concepts related to citizen engagement within energy governance and climate policy have emerged as an attempt to change the techno-centered paradigm. “Energy democracy” (Stephens, 2019) - often referred to as the political nature of energy transitions, is concerned with who controls the means of energy production and consumption; “energy citizenship” (Burke and Stephens, 2018) refers to the idea that citizens will have a key role in the energy transition. These responses humanize the energy transition by exploring new ways of thinking about public engagement and participation beyond the traditional top-down forms of governance. Both concepts relate to the same need to highlight the involvement of the social aspect of the energy transition.

For the purpose of this study, the energy transition will be viewed from a socio-technological perspective, where the different arrangements of social, economic, political and ecological aspects are reconfigured into a new (human-centered) landscape, promoted by the technology change in the quest of enhancing the wellbeing of the community. By increasing the social value of energy, the energy transition should decrease multidimensional poverty.

2.2 Sustainability assessment

More than three decades have gone by since the Brundtland Report was published (Brundtland and Khalid, 1987), and the world seems to agree that the actions promoted have not stirred enough of a change of path to be considered sustainable. Sustainability is still a big wish and is “the challenge of our time” (Sachs, 2015). Current development paths still need to change. The concept of sustainable development is evidently the basis of sustainability assessment. The following sub-sections start by outlining sustainable development, followed by an overview of the concept, and the tools and approaches to sustainable assessment.

2.2.1 Sustainable development

Focused attention on sustainable development started with the Brundtland Report, which brought the most widespread definition of sustainability and its visions: long-term conceptions and a global perspective (Brundtland and Khalid, 1987). Since then, sustainability has been on the world agenda in an attempt to move to a better and more resilient future. A first perspective on sustainable development encompasses the integration of environmental concerns and socio-economic development. Mestrum has outlined that the outcome of meeting all people’s needs through sustainable development is poverty eradication linked to environment protection, given that today’s poor are the victims of insufficient or unsustainable development. Sustainability is thus seen as an overarching concept encompassing political, economic, social and cultural development embedded into environmental concerns. The dimensions of sustainable development are parallel, interdependent and mutually reinforcing processes aimed at raising the living standards and the wellbeing of all people (Mestrum, 2003).

Additional scholars have also highlighted the interplay between environment and human activity, providing the concept of sustainable development as the result of the growing awareness of the global links between mounting environmental problems, socioeconomic issues to do with poverty and inequality, and concerns about a healthy future for humanity (Hopwood et al., 2005). Further work from Holden and Linnerud, supported by the Brundtland Report, add a third component to the sustainable development concept, as they add intra- and inter- generational equity to ecological sustainability and social needs satisfaction, pointing out that there is no hierarchy between these three major goals. They also conceptualize that additional objectives, e.g., encouragement of public participation and enhancement of people's aspirations for an improved quality of life, are subordinated to the three main components (Holden and Linnerud, 2007).

An emphasis on the idea of resource availability – scarcity - driven by population- and economic growth is embedded in the sustainability discourse (Lafferty and Meadowcroft, 2000). Another instance related to ecological limitations emerged with the carbon footprint concept in an attempt to provide a simple, comprehensive and tangible quantification of resource production and consumption, as well as the waste generated, in an attempt to translate sustainability concerns into public action (Wackernagel and Rees, 1998). An additional concept related to the relationships between environment, society and economy challenges their intersection; rather they are presented as multi-layered entities at different spatial levels in order to swap the typical view of the economy as centerpiece into a subsystem of a larger ecosystem in which the social system is embedded – a nested-model – in order to highlight the boundaries between them (Giddings et al., 2002).

Sustainable development is rooted in a process of human activity change, personal behavior, habits and lifestyles to avoid the already damaged ecological system going beyond its regenerative capacity and depletion of natural resources (Hardi, 2007). Hardi intends to define the "limits to sustainability", introducing degrees of sustainability in an attempt to provide social-ecological system boundaries. Notwithstanding diverse conceptions, sustainable development is urged as part of a global inclusive agenda, from the international level, national governments to regional actors, driven by cooperation, partnership and international law (United Nations, 2011).

In this study, *sustainability* is understood as a principle related to the interaction between social, economic and ecological systems with the aim to reach a just and equitable balance producing economic growth, increasing wellbeing, fostering social inclusion and development, alongside ecosystem conservation and regeneration towards emerging challenges. Sustainability promotes socio-economic and environmental prosperity at all levels, within society as well as with the environment.

Sustainable development for the purposes of this work is understood as the set of actions and decisions aimed at establishing an equitable cooperative and inclusive partnership at all levels within society, to conserve and protect the ecosystem whose regenerative capacity shall not be trespassed. Socio-economic growth should be interrelated with the natural resources' boundaries provision. The main aim of sustainable development should be the equity and justice provision at the social and ecological levels, which in turn should result in poverty alleviation.

The SDGs are the result of the call to action for the transformation of the world system towards sustainability (United Nations, 2015). This call requires the joint efforts of governments (at all levels), civil society, the scientific community and investors. The challenge lies in a shared understanding of how to operationalize the SDGs (Sachs et al., 2019). Each country needs to contextualize the SDGs in light of their particular situations and development levels, so performance scores will differ. Variations in geographic location, governance, technology and societal conditions make assessment results dubious when depending on general information. The Integrative Concept of Sustainability (ICoS) is an approach used in this study to overcome the challenge of operationalization of the sustainability assessment. ICoS is applied as part of a methodological framework to provide a systematic and comprehensive sustainability assessment that allows a measurement of sustainability through specific criteria of justice, a global perspective and a human-centered approach, utilising three goals and two sets of rules (Kopfmüller et al., 2001). Further analysis is provided in section 5.1.

2.2.2 Concept and approaches

Current times require that sustainability be set as the main goal to achieve, but given the disputed notion of what to include, and what not, and its complexity and subjectivity, scholars have engaged in a quest to develop tools and methods for sustainability assessment. The analysis as to how far we stand from the goal is vital, and it is imperative to understand the actions needed to move toward sustainability, and what sets us further apart. The assessment is influenced by the understanding of sustainability, as well as of the boundaries for monitoring the achievements. The classification of the existing tools, methodologies, models, approaches and appraisals for assessing sustainability varies with the criteria used, which have increased since the concept of sustainable development was recognized as separate from balancing economic wealth creation and environmental degradation.

Sustainability assessment is an approach designed to direct planning and decision-making processes towards achieving sustainable development (Hacking and Guthrie, 2008). Sustainability assessment can also be defined as the process of identifying, measuring, and evaluating the potential impacts of alternatives for sustainability (Devuyst, 2000). These concepts involve a procedural approach - steps, the estimation of the effects – impacts - of the proposed actions, and operationalization - to guide decision-makers. Indeed, sustainability assessment is not a prescribed process as such, but rather an orientation of practice which is sufficiently broad to encompass a vast range of decision-making, from the choices of individuals in everyday life through to projects, plans, programs or policies (Pope et al., 2017). Undoubtedly, sustainability assessment is supported by sustainability principles.

In this study, *sustainability assessment* is understood as an approach that intends to identify, quantify and evaluate the impacts of actions taken towards defined sustainable goals on the path to sustainable development.

Sustainability assessment has intended to provoke wider changes in the decision-making behavior of various actors - stakeholders and governments -, with the aim to shift society towards lower-impact development and more sustainable outcomes (Kurian et al., 2014). It motivates evolution through regulatory assessment requiring the provision of sustained information, the examination of alternatives, considering the views of the public and a carefully considered decision-making process (Banhalmi-Zakar et al., 2018). Sustainability assessment can be a process to generate information, ensuring that a decision is taken with the best available knowledge of its most comprehensive - (un)intentional - impacts. This could lead to choosing from the best alternatives available. Then, it could be the option most suited to solve the problem in a sustainable way. Sustainability assessment thus creates choice opportunities. Sustainability assessment can also be a performance- or governance-evaluation tool, as it allows measurement of the degree to which policies are successful in meeting sustainable development objectives (Hardi and Zdan, 1997).

Multiple tools and proposals for classification have appeared (Ness et al., 2007). The implementation of sustainability assessment is wide and steadily growing, and it varies according to the different interpretations of the concept. While there are frameworks based on sustainability principles to encompass the different perspectives and values on a rather conceptual proposal (Bond et al., 2012), operational approaches try to define sustainability criteria to implement them in a practical procedure (Hartmuth et al., 2008; Sala et al., 2015). Different attempts have been made to perform sustainability assessment implementation, with two to five intersecting pillars or dimensions (environmental, economic, political, social, cultural) or more, according to the context of the evaluation (Gibson, 2006; Mirshojaeian Hosseini and Kaneko, 2012). The dimensions of sustainability which are considered can also vary depending on the scope of the assessment; some analyses consider only social and environmental spheres, while others might include economic attributes. Over time, multiple methodologies and tools have been developed to perform sustainability assessments, focusing on different scopes - pillars or dimensions - and objectives; some focus only on a certain dimension e.g., life cycle assessment (Wulf et al., 2018), while others assist in the selection of indicators for the assessment, e.g., multi-criteria decision analysis (MCDA) (Cinelli et al., 2014). A categorization has been proposed by some authors (Andes et al., 2019; Ness et al., 2007) which includes indicators (Kopfmüller et al., 2001; Lehtonen et al., 2016), composite indices (Singh et al., 2009), impact matrix (Graymore et al., 2008), and scenario analysis (Couder et al., 2014).

2.2.3 Indicators

Multiple approaches to evaluate progress toward sustainable development have been developed and tested, in which choosing appropriate measures and organizing the information in a meaningful way is a dominant path. A central concern is to effectively communicate the result to the various actors involved, from the general public, to decision-makers in civil society and in government. Indicators are perhaps the most widely-used tools to measure progress towards sustainability, and an essential component in the overall assessment (Ramos et al., 2004).

Indicators are variables that summarize, quantify, measure and communicate relevant information. Their function is to provide structure in the complexity of information which is required to generate suitable alternatives to support decision-making for sustainable development. Measurement of sustainability through indicators is currently used by experts, governments and policymakers. The major functions of indicators are to assess conditions and trends; to compare across situations; to assess conditions and trends in relation to goals and targets; to provide early warning information; to anticipate future conditions and trends (Gallopin, 2005). Other complementary purposes include social learning through the interpretation and discussion with involved stakeholders; to demonstrate accountability and benchmarking - communicating system performance -; and identification of knowledge and data gaps (Waas et al., 2014). According to Dahl, the most significant effect of sustainability indicators, particularly in early adoption, can simply be to make a problem visible and to provide awareness to stakeholders and decision-makers (Dahl, 2012). Hence, the effectiveness of the indicators can be evaluated by the way these are implemented to influence decision-making, educate stakeholders and demonstrate accountability (Krank et al., 2013).

Measurability is one of the basic criteria that needs to be considered in the development of an effective indicator framework. Indicators should be comprehensive, accessible, accepted and promote processes that lead to courses of action to support structured and coherent decision-making. Main streams in the selection and compilation of sustainability indicators could be top-down, i.e., expert-driven, and bottom-up, i.e., stakeholder-/ community-based (Bell and Morse, 2008; Reed et al., 2006). Top-down approaches are characterized by quantitative indicators, which are developed by experts with explicit, clearly-stated methodologies. Bottom-up approaches most commonly use qualitative indicators which are developed by (local) stakeholders and with implicit, unclearly defined methodologies (Bell and Morse, 2008). Much criticism of the top-down approach is that this system fails to engage stakeholders (users) or lacks understanding about the special needs of the local community. Therefore, current trends in sustainability indicator construction aim at the formation of a hybrid combination of top-down and bottom-up approaches, in which sustainability indicators are formalized by measurement experts, but their choice depends on the local community promoting participation, to create opportunities for learning, empowerment and ownership, thus facilitating progress toward sustainable development goals (Pinfield, 1996; Reed et al., 2006).

A significant challenge lies in the availability and gathering of reliable data. This implies availability of local data whose aggregation level is important for a national indicator, for instance. Establishing a common set of local indicators can allow the coordination of efforts at local level, and thus avoid the development of multiple separate initiatives within a region. It can also prevent results from local sustainability monitoring losing regional context, and can act as a driver for local sustainability initiatives (Mascarenhas et al., 2010). With a regional scope, the indicators give local communities the opportunity to influence change, which may lead to increased participation in attaining regional sustainable development objectives, and at the same time involvement in national or global SDGs which track sustainability.

An indicator hence shows performance by measuring the distance between current or predicted values of the variable and the value of the reference. The reference in sustainability indicators is what is understood by sustainable development (Bell and Morse, 2008). Thus, sustainability indicators are operational representations of an interpretation of sustainable development which allows them to 'indicate' in which direction the system is heading. In conclusion, sustainability indicators communicate information in a structured way to support and improve decision- and policy-making in favor of sustainable development.

2.3 Scenario analysis

The development of scenario analyses to make decisions about energy pathways, technologies and low-carbon futures have been commonly applied (IEA, 2020b; Söderholm et al., 2011). Scenario analyses are useful to broaden the short-term focus to envisage the necessary changes to reach a specific goal in the future, e.g., to decrease dependence on fossil fuels; to identify if a technological innovation is enough to reach a low consumption of energy, or if social changes - attitudes and habits - also need to be modified. Thus, scenario studies help to avoid a short overview by providing a longer time horizon of a complex and uncertain future for present efficient decision-making.

2.3.1 Concept and aim

A scenario can be defined as a description of a possible future situation, including the path of development leading to that situation. Scenarios are not intended to represent a full description of the future, but rather to highlight central elements of a possible future and to draw attention to the key factors that will drive future developments (Kosow and Gaßner, 2008). Some authors define a scenario as a description of how the future may unfold based on 'if-then' propositions; a scenario typically consists of a representation of an initial situation and a description of the key driving forces and changes that lead to a particular future state (Alcamo and Henrichs, 2009). A scenario is not a future reality but a way of foreseeing the future, thereby throwing light on the present in terms of all possible and desirable futures. A common consensus about a scenario involves a description of a possible future situation and a path of development which may lead to that future situation (Götze, 1991 as cited in (Mietzner and Reger, 2005); Steinmüller, 1997 as cited in (Kosow and Gaßner, 2008))

Scenario analysis is a procedure covering the development of scenarios, comparison of scenario results, and evaluation of their consequences. A key idea is to explore alternative future developments whose goal is to anticipate such future developments of nature and society, and to evaluate strategies for responding to these developments (Alcamo and Henrichs, 2009). Scenario analysis has gained increasing importance in future planning in recent decades. Scenarios emerged as a military strategic planning tool, evolving later into the context of social forecasting and public policy by Herman Khan, and as a strategic management tool in the business community (Bradfield et al., 2005). The most widely-known user of corporate scenarios is Royal Dutch Shell, which disseminated its use to a wider group of audiences, offering an interesting, reliable picture of the future; it became a popular method to address uncertainty and to improve decision-making (Coates, 2000). At present, scenario analysis is used in a variety of different contexts ranging from policymaking, business planning, and local community management, up to global environmental concerns (Kok et al., 2011).

The aim behind scenario analysis is to generate orientation regarding future developments through an observation of certain relevant key factors. Special attention should be paid to the process, since a scenario is not a comprehensive image of the future, rather its true function consists in directing attention to one or more specific, clearly demarcated segments of reality. It is to be noted that the selection and combination of key factors with regard to a future time horizon is also a construct. That is, certain factors and events are deliberately taken to be relevant, or are ignored, and these are then brought into play and set in a context of interrelationship with one another in light of certain assumptions, which in turn can also be restructured in another way at any time. Every such scenario-construct is based on assumptions about how the future might one day look, what direction certain trends might take, what developments might remain constant, and which might change during the course of time (Kosow and Gaßner, 2008).

Scenarios do not provide exact knowledge of the future; rather, they supply a hypothetical construct of possible futures on the basis of knowledge gained in the present and past – a construct which includes, of course, probable, possible and (un)desirable future developments. The understanding of the future has an effect on the way in which we attempt to deal with it from the present position: it is predictable because what happens in the future can be calculated from our understanding of the past and present. The future is evolutive because it follows a chaotic, uncontrolled, and random path without full possible control of the course of future events. The future is malleable since it is open to intentional influence - partially- by our actions. The concept of a scenario represents the idea of a possible future and therefore always refers implicitly to the possibility of more than one other alternative futures (Dewald et al., 2019; Van der Heijden, 2005).

For the purpose of this study, *scenarios* are different alternative pathways; in this case, alternative futures which try to depict the systemic interplay between society, economy and technology. Scenarios are intended to provide orientation through a consistent process of possible, relevant, alternative and plausible developments for making strategic decisions.

2.3.2 Classification and process validation criteria

Due to their growing use, a wide range of scenario classifications and methodologies have emerged; in addition, different schools of thought have influenced diverse perspectives. However, no agreement has been reached on a general typology. A typology regarding the development and application of scenarios is often found in three categories, reflecting different perspectives about the future. Börjeson defined these as predictive, explorative and normative scenarios, with each category containing two different scenario types. Predictive scenarios are primarily drawn up to make it possible to plan and adapt to situations that are expected to occur. Concepts of probability and likelihood are closely related to these scenarios. Explorative scenarios - also called descriptive scenarios - aim to explore situations or developments that are regarded as possible to happen, usually from a variety of perspectives. They can be useful in cases when the user may have fairly good knowledge regarding how the system works at present, but is interested in exploring the consequences of alternative developments. Normative scenarios are goal directed - also called anticipatory scenarios - and respond to planning concerns in order to achieve desired targets; they are distinguished by how the system structure is treated. The focus of interest in these normative scenarios is on certain future situations or objectives and how these could be realized (Börjeson et al., 2006).

Scenarios are also distinguished by the type of information they operate, such as the degree of quantitative and qualitative data used, or which is available. Quantitative compilations such as graphs or tables are used with mathematical models in subjects like environment or economics, whereas qualitative knowledge from cultural, social or political subjects in primarily non-numerical form, often tend to the development of storylines, i.e., narratives which are typically intuitive and adapted to the variety of stakeholders' disciplines. These scenarios can describe a complex system by incorporating the views of several stakeholders at the same time (Van Notten et al., 2003). It is often desirable to combine qualitative elements – storylines - and quantitative elements – numbers - in scenarios because this makes the best use of the benefits of both types of information.

In the literature, a number of quality and process validation criteria have been identified for scenario planning. Below is a compilation of the most recurrent criteria:

- **Plausibility:** The selected scenarios have to be capable of happening, i.e., they are possible developments, although not necessarily probable or desirable (Alcamo and Henrichs, 2009; Bradfield et al., 2005; Godet and Roubelat, 1996; Kosow and Gaßner, 2008).
- **Consistency:** The combination of logic in a scenario – the paths and future visions - has to ensure that there is no internal inconsistency and contradiction, i.e., there should be coherence (Alcamo and Henrichs, 2009; Bradfield et al., 2005; Godet and Roubelat, 1996; Kosow and Gaßner, 2008).
- **Relevance:** Each scenario should contribute specific insights into the future that help to make the decision; detailed enough but not too complex (Alcamo and Henrichs, 2009; Kosow and Gaßner, 2008).

- **Differentiation:** the alternative scenarios should be clearly different enough as distinct portraits of the future (Bradfield et al., 2005; Kosow and Gaßner, 2008).
- **Transparency:** To increase scientific criteria such as traceability and legitimacy, assumptions and choice decisions should be disclosed as a means of increasing the scenarios' degree of verifiability and legitimacy, i.e., relevance and pertinence (Kosow and Gaßner, 2008).
- **Novelty:** the scenarios should challenge the organization's conventional wisdom about the future – creativity - (Alcamo and Henrichs, 2009; Bradfield et al., 2005).

2.3.3 Scenario techniques

The literature identifies three major approaches or schools of techniques for the development of scenarios (Bradfield et al., 2005; Kosow and Gaßner, 2008), known as probabilistic modified trends, intuitive logics and prospective thinking. This section provides a brief overview of each approach.

The probabilistic modified trends methodology evolved out of the work of Helmer and Gordon, and incorporates matrix-based methodologies such as trend impact analysis (TIA) and cross-impact analysis (CIA). These techniques involve expert judgments to identify the occurrence of events and their expected impact in order to adjust extrapolations. The development of TIA arose to overcome the reliance of traditional forecasting methods on historic data extrapolation without considering the effects of unprecedented future events. So this approach combines traditional forecasting techniques such as time series analysis with qualitative factors to strengthen the scenario analysis (Bradfield et al., 2005). Cross-impact analysis (CIA) technique has been used in many different contexts. In this approach a range of causal and correlation cross-impact variants are developed in a cross-impact matrix. The underlying principle for the development of this approach was that it is unrealistic to forecast an event in isolation without considering the occurrence of other key impacting events. Therefore, cross-impact analysis is used to capture the interrelationship between key influencing factors (Gordon, 1992). Although TIA and CIA began as mainly probabilistic forecasting tools, they generate a range of alternative futures rather than a single extrapolated point based on historical data, and when combined with judgments and narratives from experts about the events in these futures, they constitute scenarios (Kosow and Gaßner, 2008). Further detail about cross-impact analyses follow in chapter 5.

Intuitive logics methodology dominated Anglo-American Corporation scenario planning development in 1970s. It was earlier proposed by Kahn and used at Royal Dutch Shell and other global business networks, hence it is also referred as the 'Shell approach' to scenarios (Khakee, 1991). The intuitive logic approach allows for estimates and uncertainty evaluations in addition to objective data and their analysis. The intuition of experts acts as its reference points, i.e., those actively involved and most familiar with the recognition of inherent structures develop new ideas on decision-making processes, mainly challenging conventional thinking to reframe perceptions and change mindsets. The entire process is decision-oriented and allows a high degree of connectivity, since the approach embraces and integrates consideration of the full set of political, economic, social, technological, ecological and legal factors that will shape the future. This technique strongly relies on the knowledge, commitment, credibility and communication skills of the involved experts. Some of these key environmental forces are precise, quantitative and predictable, but in contrast many other factors are not, such as customers' attitudes, politics, financial conditions, product demand, etc. (Wright et al., 2013).

Prospective thinking (known also by its original French name "La prospective") was developed by Berger and Jouvenel, and continued by Godet and Roubelat, who developed a number of computer-based tools to analyze structural conditions and stakeholder positions. The main underlying aspect of this approach is that the future is not predetermined; it can deliberately be built and cannot be conceived as a simple continuation of the past. This approach develops normative scenarios of the future and articulates idealistic future images so that scenarios can serve as a guiding vision to policymakers and provide a basis for future action (Godet and Roubelat, 1996).

2.3.4 Scenario uses

Mathematical models used in quantitative energy scenarios are the standard way to inform stakeholders about possible futures and the consequences of political decisions (Dewald et al., 2019). Most of these models focus on particular aspects of the energy system, e.g., techno-economic models draw attention to energy technologies analysis and neglect an adequate representation of market relations. Attributes which are outside the immediate energy system, such as economic and social developments, innovation, changes in preferences, social values or consumer behavior are usually treated as fixed framework assumptions despite their existence and influence are undeniable. Moreover, these factors also convey a certain degree of uncertainty, which model-based energy scenarios address through a sensitivity analysis. Possible interdependences between the individual elements that determine the framework conditions are not considered, therefore, insufficient attention is paid to them, and to the uncertain assumptions questioning the reliability of these models (Weimer-Jehle et al., 2016).

The Cross-Impact Balance (CIB) analysis emerged as an alternative technique for constructing qualitative scenarios, which can be elaborated into storylines through the description of the context in a more systematic and formalized way (Weimer-Jehle et al., 2016). The CIB method can be understood as a heuristic procedure that supports the analysis of qualitative knowledge about the interdependence of system elements. Given the nature of the complex systems as socio-technical systems, qualitative information is as important as quantifiable knowledge, hence, for CIB purposes, both types of input data can be included in the scenario-generating process. This method is capable of evaluating qualitative impact networks in the same way as quantitative ones; for this reason, the application fields are multiple and interdisciplinary. The CIB method is suitable to combine context scenarios with model-based energy scenarios. The basic idea is to take the context scenarios as an (additional) input for the calculation of the model-based scenarios; albeit the coupling of context scenarios with model-based energy scenarios involves methodological challenges (Dewald et al., 2019). Merging the qualitative context scenarios with quantitative model output results in a consistent description of one possible future of the combined system - "context system and energy system" (hybrid scenarios), explaining the interplay between both system parts. The resulting set of socio-technical energy scenarios can be useful to study the uncertainties of conclusions drawn from the scenario analysis, to identify socio-technical opportunities, challenges and conditions for energy goals, as well as to develop strategies into a desired energy pathway. Details of the procedure of CIB analysis is explained in section 5.2.

Scenario building has proved useful as a tool for supporting sustainable transitions of societal systems, including processes of mobility, land use and economic development, and has been used in transdisciplinary settings to facilitate and reorganize future institutional structures and to counsel decision-makers (Wiek et al., 2006). Energy scenarios are social constructs that can contribute to decision-making in dealing with complexities and uncertainties through discussion of alternatives and diversity of energy futures (Grunwald, 2011). Attempts to use scenarios to assess technologies from a sustainable perspective have emerged that consider social, environmental, technical and economic aspects promoting multidisciplinary work (Ibáñez-Forés et al., 2014), however, the process is dependent on decision-makers' judgments. Sustainability assessment of scenarios has been recognized as a significant topic where there is not an agreed methodology that can be used, which requires attention and further discussion due to lack of research into the systematic analysis of both concepts (Fauré et al., 2017). Some proposals intend to address this lack; a framework developed for assessing environmental and social features presents a guideline focused on qualitative results based on narratives (Arushanyan et al., 2017). Additional studies have focused the analysis of the sustainability impacts of future scenarios from the Information and Communication Technologies (ICT) stance, using explorative scenarios for policy (Pargman et al., 2017). A methodology based on the qualitative narrative guideline focuses its attention on the assessment of social aspects in a set of future scenarios is also limited to the ICT perspective (Ekener, 2019). Another methodological framework was proposed to analyze the sustainability of future visions from the system design viewpoint in (Halbe and Adamowski, 2019).

Few studies and little attention have addressed future scenarios under a sustainability assessment that can suitably integrate social, environmental, and technological contexts in a systematic way. One of the latest research suggestions for an integrative methodology is presented as an attempt to improve scenario assessment of energy systems transitions through the use of a complex tool based on CIB scenarios and model-based as well as non-model-based indicators, as an effort to improve the discussion on socio-technical energy system transformation scenarios (Kopfmüller et al., 2021). However, no further studies have been found to deepen energy transitions' sustainability assessment of scenarios. From the methodological perspective, the present study intends to add to the discussion in an effort to close the gap on the comprehensive integration of scenario analysis and sustainability assessment in a systematic approach, which addresses social, economic, technical, environmental and political features. The detailed description of the proposed method of *Scenario-based sustainability assessment* is provided in chapter 0.

"I, a son of ancestral lands,
am not invisible before your portrait,
I am a native of healthy mountains,
lung of 'the people of the rain'"

— Samuel Leyva (2023)

"Yi'i, ni taa ñuu ka'no,
vasa kuy ndiwa'a no xinon,
kuy yivii uku tiku'i,
Nima yivii savi ni'i yi'i"

—Samuel Leyva (2023)

3. Rural Mixteca: status quo

This chapter 3 along with previous chapter 2 and the subsequent chapter 4 belongs to Part 2 of the dissertation; the case study presentation (see chapter 0).

The Mixteca region includes parts of the three Mexican states of Guerrero, Oaxaca and Puebla. This research focuses solely on the Mixteca region of the state Puebla. Mixteca in Puebla is located in the southwest of the state (see Figure 2). The Mixteca region covers an area of 11,025 km^2 representing 32.5% of the state's territory, and 45 municipalities conform the region (see Appendix A). Its population of 273,096 inhabitants is scattered across 472 locations, representing 4.2% of the total Puebla state population. About 90% of the population in Mixteca lives in communities with less than 5,000 inhabitants, and essentially Mixteca is considered to be a rural region (INEGI, 2021).

Figure 2. Location of Mixteca region in state of Puebla, Mexico

3.1 Geographic conditions

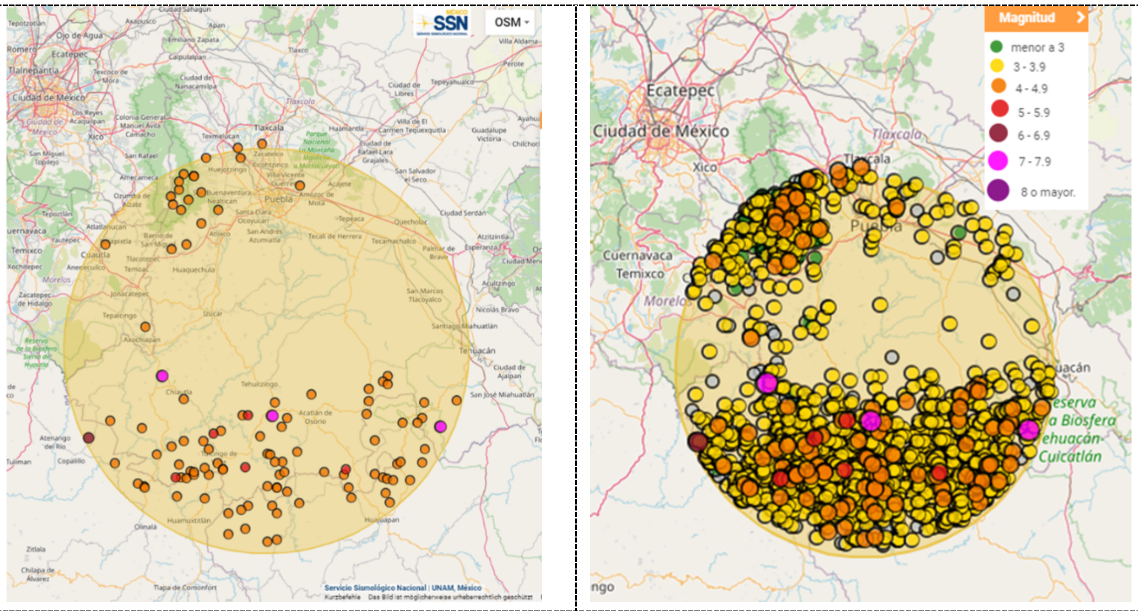
Mixteca is located between the intersection of the Neovolcanic Axis and the Sierra Madre del Sur, thus most of the terrain is mountainous. Temperature, climate and precipitation depend on the altitude of the territory, which in turn influence forms of land exploitation. Altitude varies between 700 and 2500 m above sea level. Vegetation is low deciduous forest with a predominance of bushes (thorny legume trees), cactus and grasses, *maguey* (a type of agave); low thorny forest, thorny shrubs, and small areas of oak woods, and grasslands. The average annual rainfall fluctuates between 700 to 1100 mm mainly during summer months; the rest of the year rainfall is scarce. The weather is semi-dry, very warm, and the temperature oscillates between 19 to 27°C, with a steady temperature of 25°C (Gobierno de Puebla, 2011; INEGI, 2021).

There are four main type of soil: leptosol (lithosols) represent soils with less than 25 cm thickness or with more than 80% of their volume occupied by stones or gravels and are very susceptible to erosion by various human activities. Luvisol: red, gray or light brown soils, susceptible to erosion, especially those with a high silt content and those located on steep slopes. Fluvisol soils with abundant fluvial, marine or lacustrine sediments. Vertisol heavy soils under alternating saturated-dry conditions, with wide, abundant and deep cracks when dry and with more than 30% expandable clays. With a good tillage and drainage program, these soils are fertile for agriculture due to their high moisture-retention capacity and their mineral exchange properties with plants. Construction works on these soils must have special specifications to avoid damage due to movement or flooding. The arid landscape and harsh geographic conditions make Mixteca's soil unsuitable for agricultural activities (Gobierno del Estado de Puebla, 2011; INEGI, 2021). Figure 3 provides some images of the topography and landscape in the region.

Figure 3. Aerial view of the municipality of Xayacatlán de Bravo (top) and landscape in Mixteca (bottom).

3.2 Seismicity and vulcanism

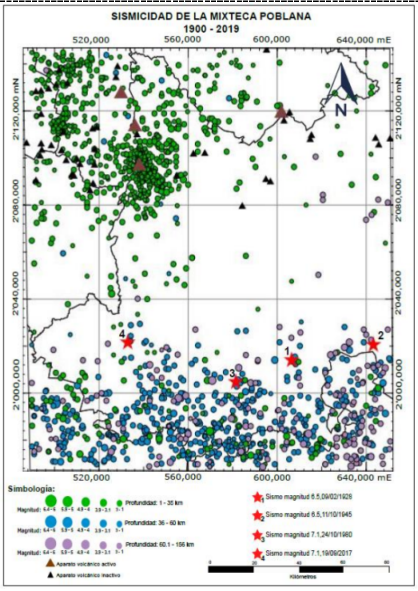
Mixteca is located in a seismic zone, surrounded by states (Guerrero, Oaxaca and Chiapas) with a high incidence of earthquakes due to the subduction (submersion) movements of the tectonic Cocos and Rivera plates under the North American and Caribbean plates (Pérez Campos, 2016). The last 40 years have recorded 90 seisms in Mixteca higher than 4 magnitude (light to moderate movement); of them, 3 have been recorded above 7 magnitude (strong). The last and strongest earthquake (7.1 magnitude, 51 km deep) took place in September 2017; its epicenter was located within Mixteca (8 km north Chiautla, the second-most developed locality) (Servicio Sismológico Nacional, 2022). Effects were registered in 7127 km^2 within Mixteca; where 24 municipalities out of 45 recorded 14,895 houses and buildings (churches, governmental offices, schools, public markets) severely damaged (Jiménez Morales, 2020). Five years later, the inhabitants still encounter the challenge of lack of reconstruction of houses and buildings due to their vulnerability (Hernández, 2022; Vázquez, 2022). Figure 4 shows the incidence of earthquakes in Mixteca due to the tectonic plates (author's calculation from data and map from (Servicio Sismológico Nacional, 2022)).



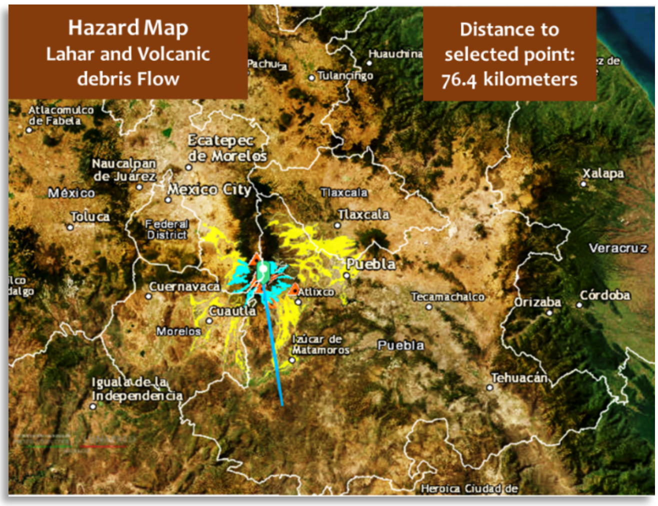
From January 1980 to October 2022, 90 earthquakes higher than 4 Magnitude have been registered in Mixteca (lower part of the area within the circle)	From January 1980 to October 2022, 1530 earthquakes all Magnitudes have been registered in Mixteca (lower part of the area within the circle)

Figure 4. Map of seismic activity in Mixteca. Source: author's calculation from data (Servicio Sismológico Nacional, 2022)

Within the mountainous chain, a series of volcanoes located in the surroundings of the state of Puebla (Popocatépetl, Iztaccíhuatl, Matlalcueye, Citlaltépetl) are worth considering, not only because of the contribution of seismicity but also due to the possible effects of volcanic activity. From this series of volcanoes, the one that has currently been identified as having the potential to affect Mixteca is the Popocatépetl volcano, which has been active in recent years through lava expulsions, lahar detachments, landslides, collapse of slopes, soil erosion and ash emissions; this volcano is located at a distance of approximately 77 km north of Mixteca (CENAPRED, 2022).



a) Seismicity map from Mixteca, period 1900-2019, caused by: volcanoes (top area) green dots represent a seism caused by a volcano (brown triangles); and seisms caused by tectonic plates movement (bottom) where red stars signal a major earthquake. Source: (Jiménez Morales, 2020)



b) Map displaying the estimated debris flow in case of a major collapse (eruption) from volcano Popocatépetl. Blue flow exhibits the most likely affected area with volcanic debris flow. The yellow flow signals the lahar and ash dispersion area. The blue line lays out the distance to Mixteca. Author data input based on model from (CENAPRED, 2022)

c) Aerial map of smoke and ash flume from volcano Popocatépetl. Photo from (Satellite Copernicus Sentinel and Markuse, 2021). Image represents about 23 km wide overview.

Figure 5. Maps showing possible effects of volcano Popocatépetl in Mixteca.

3.3 Ancient Mixteca Culture

In order to understand the current socio-cultural and political (how decisions are taken within society) present life in Mixteca, it is necessary to understand its past. History tells us that Mixteca[1] culture was one of the fourth most important cultures in pre-Hispanic Mexico (INAH, 2008). It is estimated to have emerged around year 1500 BC. Mixteca was a dynamic culture with strong social, political and economic movements, which interacted not only with the ethnic groups, towns, valleys and sub-regions of the area, but also with other regions and ethnic groups of Mesoamerica. Mixtecos were peasants, they cultivated and subsisted on corn, beans and squash; a basic diet supplemented with domestic plants such as *maguey* (type of agave), *nopal* (type of cactus), chili, avocado, *zapote* (sweet soft fruit) and amaranth. Although most of the products they consumed were already cultivated, they collected a wide variety of wild plants, nuts, tubers, cacti and fruits that they used for food, medicine and other practical and ceremonial uses that still persist nowadays (Spores, 2018).

The Post-classic period (900-1521) was a time of prosperity, reflected in its complex settlement pattern, social stratification, intra- and inter-regional relations in the commercial, political (marriage alliances), social (presence in other cultural regions) and religious spheres (regional sanctuaries). Pre-colonial Mixteca culture is recognized for its artistic works in precious metals (gold, silver, copper), precious stones (mosaics of turquoise, obsidian, flint, *chalchihuite* or green stone, rock crystal and tecali), bone, polychrome ceramics, architecture and codices (INAH, 2008). Some examples are shown in Figure 6.

Pectoral
Material: Cast gold
Source: Tomb 7, Monte Albán, Oaxaca (1250-1521)
Current location: Museum of Cultures, Oaxaca-Mexico

The pectoral represents a personage with a zoomorphic helmet, adorned with feathers and lateral rosettes from which hang strips, earrings adorned with protruding snakes, it presents a fleshless mouth mask held with a thread under the nose, in the torso area presents two decorated quadrangular plates, on the left side with the god Cocijo accompanied by glyphs and on the right side a calendar date (representation of the year).

Photo: INAH (National Institute of Anthropology and History)

[1] Throughout the following paragraphs, when addressing Mixteca in pre-Hispanic time or its evolution up to the 18th century, it is referred to as the region framed between the states of Puebla, Guerrero and Oaxaca, since Mexico as a country and its contemporary political division and state boundaries did not exist.

	Codex Bodley or 'Codex Ñuu Tnoo-Ndisi Nuu' Material: Strip of 6.70 m long deerskin folded into 20 sheets painted on both sides. Source: Tilantongo, Oaxaca (before 1521). Current location: Bodleian Library, Oxford-U.K. The codex is a pictorial screenfold manuscript representing the genealogy and rituals of the royal families in the ancient dynasties of Tilantongo, Tiaxco and Achiutla (now Oaxaca in Mixteca Alta), from the 10th to the 16th centuries. Photo: Bodleian Libraries, University of Oxford CC-BY-NC 4.0.
	Fretwork on stone murals in Mitla Material: Stone carvings Source: Mictlán, "Resting place of the dead, Lyobáa" (200-1521) Current location: Mitla, Oaxaca Five groups of monumental architecture are the evidence of ancient Mitla: the North, the Columns, the Stream, the Calvary and the South Group. Photo: INAH (National Institute of Anthropology and History)

Figure 6. Cultural elements produced during the pre-Hispanic Mixteca period. Sources: (Cultura Mixteca, 200-1521, 1250-1521, before 1521).

Epidemics played an important role in the consolidation of the Spanish Conquest in the early 16^{th} century. It is estimated that by the time of the Conquest 700 000 people inhabited Mixteca; by 1590 the population had decreased to 57 000, and by 1670 only 30 000 inhabitants were left (Spores, 2018). Despite the forced conversion to the Catholic religion brought by the Spanish, and the persecution of native polytheist religion, Mixtecas embraced the new European technology, the Spanish language and the colonial political-economic system. The traditional temples were destroyed and Catholic churches were built on their foundations. The art of writing on deer skins was abandoned and with it, the codices entered the realm of interpretation rather than reading and declamation (Aguilar Sánchez, 2020). Nevertheless, the population did not give up their native language and retained much of their traditional and cultural life. Pre-Hispanic crops - such as beans, corn, chili and squash – continued to be harvested, but new European seeds, plants and fruits were successfully introduced. However, the main sources of income were silk, cochineal insect and small livestock - sheep and goats (Escárcega and Varese, 2004).

After the decline of the native population as a consequence of the Spanish Conquest, many cultivated terraces were abandoned or used for raising livestock (goats). These changes contributed to soil erosion and the impoverishment of the inhabitants, who had to look for new economic alternatives. The first of these was palm weaving (still a source of income), and the second alternative was emigration.

3.4 Emigration and economy

Researchers estimate emigration started during the 19th century (Clark Alfaro, 2008), (Spores, 2018), (Escárcega and Varese, 2004). A combination of economic factors and a growing demand for unskilled labor in agriculture and other emerging sectors in the USA resulted in the emigration of hundreds (thousands followed with time) of inhabitants of Mixteca who started the emigration wave. These first emigrants - of a total of 4.7 million temporary Mexican workers - joined a program the USA designed – the Bracero Program - to compensate for its lack of labor. Over time, the demand for labor exceeded the program, creating a flow of undocumented migrants (Durand et al., 2016). In 1965, the focus of USA immigration policy shifted to family reunification, eliminating almost all the other options for temporary legal entries. However, the demand for labor continued to increase, creating a large, undocumented, circular flow. In addition, the north Mexican border joined the industrialization movement as a response to the high emigration flows looking for jobs. The maquila industry grew and flourished due to the flows of emigrants who did not have the chance to cross legally to the USA. Mixteca emigrants who used to live under vulnerable conditions and poverty in their home region endured harsh conditions in low-skilled jobs (agricultural and maquila) in north Mexico. Agro-industries and maquila factories realized the indigenous population had advantages to their economic purposes: they offered low-skilled labor, they were desperate for jobs and illiterate, hence the indigenous people did not know about their rights, most of them spoke only their native language, and thus they were easy to manipulate to endure long working hours in harsh conditions. Recruitment started from their place of origin, in Mixteca itself, and job offers included buses that facilitated the transportation of people to the factories in north Mexico (Clark Alfaro, 2008).

Undocumented flows are difficult to count. The number of apprehensions at the border can be used as a proxy for undocumented annual entries (Department of Homeland Security, 2017). Measuring migration flows between Mexico and the USA is challenging because there are no official counts of how many Mexican migrants enter and leave the USA each year. Mixteca has been recognized as one of the well-established flow regions of mostly undocumented low-skilled agricultural labor migrants moving to the USA, and / or emigrants who make border cities a home base for making repeated, mostly undocumented, trips to the USA (Fussell, 2004). In 2005, around 35,800 Mixteca emigrants were located in three north Mexican states - Baja California, Sonora, Sinaloa - (Clark Alfaro, 2008) with data from (INEGI, 2005). It is important to note that this figure includes the Mixteca population from the second and third states sharing the Mixteca region (Oaxaca and Guerrero). It is already difficult to document emigration flows, but even harder to ask for a precise location of origin when Mixteca inhabitants identify themselves by their ethnic origin and not by the political division of land within the country (states). It would have been interesting to compare patterns with the present day figures, but unfortunately, there is no updated information available, see (Instituto Nacional de los Pueblos Indígenas, 2022) with information unavailable from (INPI, 2010).

Mixteca emigrants are more likely to be males of working age, from 18 to 64 years old, which is the reason why the proportion of women living in Mixteca is on average 20% higher than men; reaching 25% in the range from 25 to 30 years old. The share of females under 18 years old is 49% (INEGI, 2017). Because emigrants usually leave women behind who then become responsible for household and community decisions, women can achieve a non-intended partial empowerment. Thus, population distribution in Mixteca has a higher share of women, as seen in Figure 7.

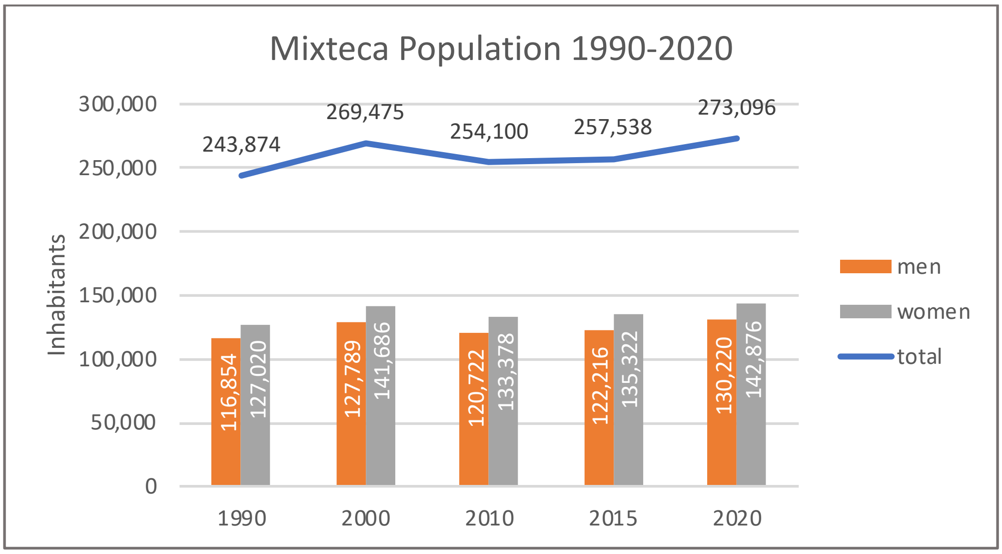


Figure 7. Mixteca population distribution over the last three decades. Source: Author's calculation per data from (INEGI, 2020b; INAFED, 2010; CONEVAL, 2018b)

Remittances make up monetary flows related to emigration, mainly to the USA. They are an important income source, manifesting a high degree of economic dependence not only for families, but also for the whole of rural Mixteca. Households' use for remittances in the region are mostly for food, clothing, health expenses, debt payments, family education and household goods; they are basically to compensate for lack of income. Remittances have increased over the past years, providing support for private consumption, particularly in low-income families (see Figure 8, author's calculations based on data from (Consejo Nacional de Población and Fundación BBVA, 2019)). In 2020, Mixteca contributed 13% of the total received remittances in the state of Puebla, representing 243 million USD, although only 4.5% of the entire population of the state lives in Mixteca. In 2020, the state's contribution to national participation in remittances represented 5.5% of the country's Gross Value Added. It is considered that a bigger share of what is reported is subsequently distributed to Mixteca, adding this to the reported local figure.

Remittances can also be used for collective and public infrastructure investment for the benefit of the entire community, e.g., paving streets, improvements in local schools, local markets, the town's civic center, or for the yearly religious festivity (the patron saint of the town); highly appreciated social activity whose planning takes around one year and involves a considerable amount of work and funding. Remittances are considered a relatively stable and secure contribution to family income, despite the fact that for the counterpart of origin, it is dependent on employment stability (Rivera Sánchez, 2004). Remittances have been recognized to contribute to alleviating scarcity, but research has (still) not provided evidence on the contribution to decreasing poverty. The contribution of remittances is often ignored when measuring poverty. Remittances predominantly are used as part of an income-generation strategy for households rather than to stimulate a reduction in labor supply. The typical role of emigrants is remittance delivery to their communities of origin. Figure 8 shows Mixteca's share in remittance delivery within the state. As the trend shows, remittances consistently tend to increase, except for 2017 where records cannot be precise if the amount delivered through the capital city was allocated to Mixteca municipalities (author's calculation based on data from (Consejo Nacional de Población and Fundación BBVA, 2019)).

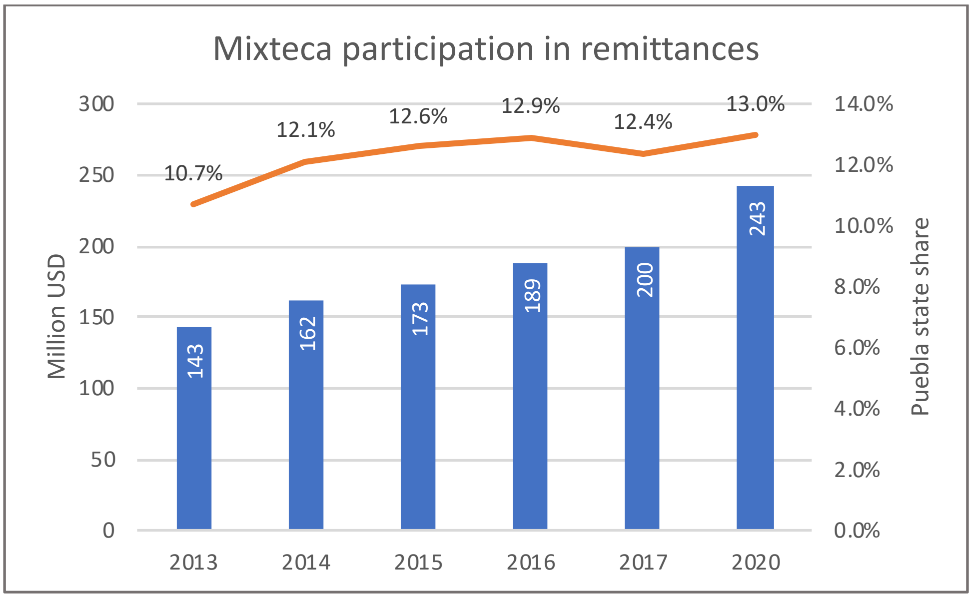


Figure 8. Inflow of remittances to Mixteca and share of state participation. Author's calculation per data from (Consejo Nacional de Población and Fundación BBVA, 2021)

The scarce development of agro-industrial activities with commercial capacity, related mainly to the mixed-race *mestizo* population and not to the native communities, determines an environment in which subsistence agriculture is dominant. Rain-fed crops employ family labor in the production of corn, beans, poultry and goats; other domestic activities are linked to the manufacture of hats, palm weaving and handcrafts made from onyx or pottery. Some of these activities are linked to migratory flows (Rivera Sánchez, 2004). The low productivity of these activities partly explains the meager wages; inadequate working conditions prevail in harvesting, small-scale trade and labor work in maquila factories, which prevent the population from meeting their basic needs.

Nearly 91% of the economically-active population in Mixteca earns less than 2 minimum wages - around 248,000 inhabitants - (INEGI, 2020b). Family income has not depended on a single activity, nor on the work of only one of its members. The diversity of economic activities reflects the insufficient income generated by each of these activities and the precariousness that characterizes them in terms of working conditions.

Only 27% of the population in Mixteca belongs to the working population sector. The working population is defined as those who have a job or income from formal economic activities contributing to the GDP. Informal jobs are not accounted for in this category. The working population term should not be mistaken for the economically-active population. Only about 2.5% of the working population is enrolled into the social security system. Of those, around one quarter are farmers and livestock workers. From the total working population share, 40% of people perform activities related to the primary sector (agriculture, livestock – goat -, forestry and mining

- onyx, marble), around 25% work in the secondary sector (factory employees – maquila -, workers in basic and support activities, artisans, construction workers), 12% contribute to trade and retail activities (groceries, food products, textiles, footwear); the remaining 23% of the working population address the customer services sector.

Around 10% of the working population are government officials, professionals, or technical and administrative personnel. The main activities of the manufacturing industry are food processing – poultry -, textiles, small leather-related activities, production of stone products, clay extraction and pottery (ceramic). The added value of economic activities in Mixteca represents 0.20% of the state's added value. During 2019, Mixteca received funding from the State Government for economic development equivalent to 2% of the total allocated to the state. For social development, Mixteca received 7% of the state total (author's calculations based on information from (INEGI, 2020a, 2020c, 2021)).

3.5 Poverty

Poverty in Mixteca is a reaction to multiple factors, from scarce economic activity to low wages which cannot cover basic needs, leading to poor health conditions and scarce or no savings for investment; in addition, low levels of schooling turn into low capacity-building that goes back into the vicious circle of poverty. Figure 9 shows the poverty status quo in Mixteca per the multidimensional concept of poverty explained in section 2.1.1.

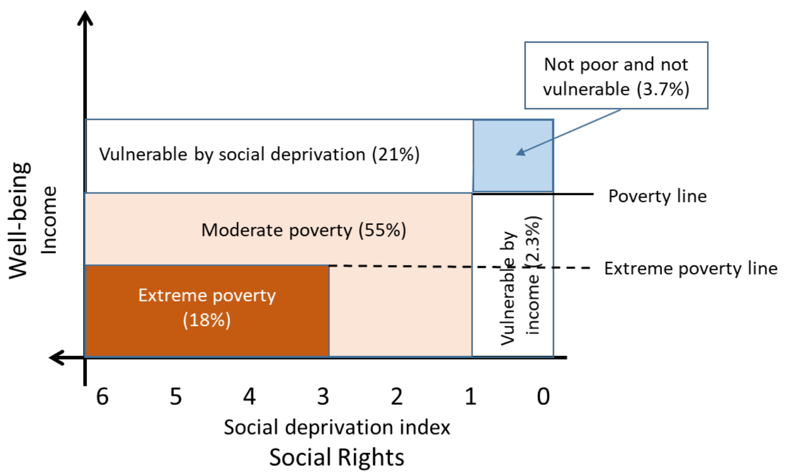


Figure 9. Classification of poverty within population in Mixteca. Source: author's calculation per data from (CONEVAL, 2020; INEGI, 2021)

Around 202,000 inhabitants in Mixteca, representing 75% of the population, live below the income poverty line (author's calculation per data from (CONEVAL, 2020; INEGI, 2021)). Furthermore, they are deprived in at least one of the social dimensions that constitute the multidimensional concept of poverty.

About 18% of the population under the income poverty line experience extreme poverty conditions. Their income is below the cost of the basic food basket and is accompanied by three or more social deprivations. While it is true that extreme poverty showed a decrease from 2010 to 2020 of about 9%, the moderate poor increased in the same period by about 6%, as well as social deprivation vulnerability which increased by 2%. The percentage of the population not suffering from any deprivation and being non-poor, improved 0.8% in the ten-year span, representing about 10,270 inhabitants. A chart showing the last decade performance on poverty and vulnerability is presented in Figure 10 (author's calculation per data from (CONEVAL, 2020; INEGI, 2021)).

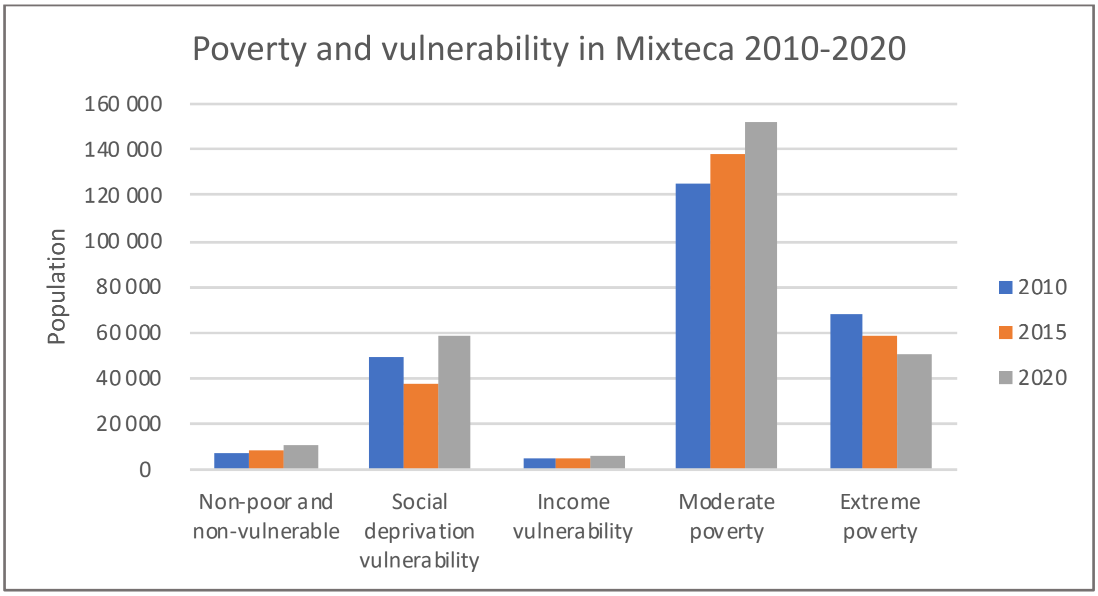


Figure 10. Poverty and vulnerability development in Mixteca – Puebla

Nevertheless, the fact that three-quarters of the population is under a certain poverty degree, in addition to the 21% of the population suffering from a particular vulnerability, places the region as poverty-ridden and gives Mixteca a challenging perspective for future growth.

García and Graizbord have provided an overview of energy poverty in Mexico through energy services access where geographical specificities were encountered, among them, rural location was a strong predictor of multiple service and clean cooking fuel deprivation. Warmer climate zones were a strong predictor for those lacking ventilation or air conditioning. 87% of those in the most severe energy poverty description, i.e., lacking 5 out of 6 essential energy services identified in Mexican households - water heating, cooking, refrigeration, lighting, thermal comfort and entertainment - were located in warm climate rural areas such as Mixteca. For the purposes of this research, this concept of energy poverty will be used, which is defined as "the lack of certain energy services which are essential to cover human needs linked with these services" (García Ochoa and Graizbord Ed, 2016).

Based on an expenditure approach, Seuret-Jimenez et al., classified the 32 states of Mexico according to their level of energy access – high, medium, or low – based on expenditure on transport, cooking fuel and electricity. They identified that around 53% of the country lies within low energy access or on the border of low and medium; 19% with medium energy access; and only 28% with high energy access. They also found that the patterns of expenditure on energy access broadly follow the GDP per capita average per state. Across these metrics, they found that 19.6 million households were facing energy poverty in Mexico (Seuret-Jimenez et al., 2020). Consequently, in addition to the vulnerabilities explained above, Mixteca is also an energy-poor region with low energy access, mainly due to its multidimensional poverty status but also due to its geographic condition. See Figure 11.

Both approaches have distributive justice implications and point to the need for research that integrates both energy expenditure and energy services-based approaches, in order to configure an inclusive concept of energy poverty, which is currently missing in Mexico.

Collected wood and branches of trees for heating purposes.

Branches, biomass and charcoal used as cooking fuel and lighting.

Figure 11. Cooking fuel, heating and lighting in Mixteca houses. Photos by the author.

Characteristic of the poverty in Mixteca is the high relevance of structural deficiencies related to the precariousness of housing, its materials and lack of basic services. There is evidence that inadequate floors, wall and roof composition are connected to poor indoor air quality and increased likelihood of respiratory illnesses (Bradley and Putnick, 2012). Dwellings in Mixteca display qualitative deficiencies; 91% have either dirt or solid ground floor and 39% have roofs of discarded material, such as corrugated sheets of wood, palm or metal.

Dirt floors are known to harbor parasites and bacteria which can cause serious health conditions, including diarrhea, parasitic infections, respiratory illnesses, anemia, immunodeficiency and malnutrition (Bradley and Putnick, 2012). Qualitative deprivation of housing is also a common living condition in Mixteca, where 28% of the population inhabits overcrowded circumstances.

Regarding water provision, 37% of the households in Mixteca have access to a pipe within the dwelling. About 10% of the population collect their water from public taps, tube wells, boreholes, from a neighboring house, truck pipes, water body or rainwater. The remaining 53% have access to water outside their house but through the public pipeline (INEGI, 2021). When water is not piped and served into the house, the storage of water becomes a major issue as regards contamination. An important remark on water provision is that water is mostly not of drinking quality. Sanitation access through the public sewage system serves 55% of the population, close to 25% use a biodigester, and around 20% lacks a sanitation facility or uses one that does not ensure hygienic separation of human excreta from human contact (in cliffs, ravines, rifts or water bodies). Under the government development action plans, sewage disposal in cliffs, ravines, rifts or water bodies counts as acceptable sanitation disposal (Gobierno de Puebla, 2019c), so the official figure for sanitation access rises to 95%.

Access to safe drinking water, improved sanitation, refrigeration (electricity access needed), as well as other related living conditions, such as high-quality housing materials (see Figure 12) and a closed stove, all increase the likelihood that young children will avoid diseases like diarrhea that could lead to malnutrition or even death. It also increases the likelihood to avoid serious respiratory illnesses. Records show that during 2018, around 800 children younger than 5 years old died in small localities (less than 5000 inhabitants) with respiratory illnesses and intestinal infectious diseases among the causes (author’s calculation based on data from (INEGI, 2021)).

Houses in Mixteca, roofs of corrugated metal, walls of discarded materials (top) and adobe bricks (bottom). In both cases, the electricity transmission grid can be appreciated along the unpaved dirt road.

Figure 12. Characteristics of dwellings in Mixteca. Photos by the author.

In addition to the low access to basic infrastructure, the quality of the provided services is poor. The water service quality is intermittent; electricity, currently supplied through fossil fuels generation, is delivered under a poor technical and commercial efficiency (Centro de Estudios Sociales y de Opinión Pública, 2018), which makes it unviable to use for productive purposes. Lack of access to electricity is acknowledged as a sign of marginalization and vulnerability (Comité del centro de estudios de las Finanzas Públicas, 2007; United Nations, 2020). The lack or inadequate provision of basic services, in particular of energy, has a major impact on women, who are typically responsible for collecting and managing traditional sources of fuel – biomass. Additionally, since mostly men – husbands and brothers – are emigrating, women are increasingly in charge of households and communities, partly impeding the required empowerment of women. Time spent on activities that can be avoided with modern technology could release the burden, and women could engage in productive activities.

3.6 Education

The education system in Mixteca is ruled by the national compulsory schooling system which spans from basic education (elementary and lower secondary) to upper secondary education to be completed by the age of 18 years. Half-day schooling is dominant (morning or evening shifts) but effective learning time is short mainly due to many students participating in domestic activities or having a job. Completion of basic education is still a challenge, and about 52% of the population in Mixteca of 15 years and older do not have basic education; in addition, around one-third of the population has an educational gap (almost 80,000 inhabitants) (CONEVAL, 2020).

Around 35,000 inhabitants are illiterate in Mixteca; nearly 13% of the population (author's calculation based on (INEGI, 2021)). While Puebla has made significant progress in reforming its education system in recent years, further improvements are needed in the access to, and quality, equity and relevance of the education system. Educational opportunities and outcomes are strongly related to socio-economic background and location. Students from socio-economically disadvantaged backgrounds are almost four times less likely to enroll on time in upper secondary school than those from advantaged backgrounds. Even if disadvantaged students are enrolled in education, they tend to fall behind their more advantaged peers. Those from indigenous groups are particularly at risk as they face multiple obstacles to succeeding at school, since the process to provide education in native languages is limited and usually poorly structured. As a result, indigenous language speakers have, to a greater extent, an insufficient level of achievement compared to other students (INEE, 2019).

The state of Puebla is responsible for the schooling system including remote rural areas. Municipalities have few responsibilities for education and their role is usually limited to infrastructure issues. Many of the poorest schools lack the administrative capacity to apply for funding, which exacerbates disparities between schools. Schools operate under challenging conditions, with little autonomy, and within a rigid and hierarchical system in which education policy is often characterized by isolated actions, with no planning and co-ordination between them. School support strategies tend to be fragmented, of heterogeneous quality, and are poorly coordinated and integrated. School principals do not hire or remove teachers and have little say in teacher appraisal, training, or granting incentives and career rewards. 70% of school principals report high rates of absenteeism, late arrival of teachers, and a lack of pedagogic preparation as factors that hinder instruction and reduce the quality of teaching (OECD, 2016).

Mexico's education system is relatively weak despite significant public investment in the sector. Children in Mixteca face unequal educational opportunities, and the quality of education services that reach these communities remains low. Consequently, the average time spent in education in the area is less than 6 years. The vast majority of schools lacks facilities such as laboratories, libraries or sport facilities; more strikingly, they lack basic services. Figures for Mixteca are not available, but those for the entire state of Puebla show that 18.5% of the public schools do not have toilet facilities, 28.2% do not have electricity, and 27.8% do not have running water (OECD, 2016). Given the deprived conditions of Mixteca, the percentages for the area should be higher, since 80% of the community primary schools are located in populations with a high- or very high degree of marginalization (INEE, 2019).

3.7 Financial system

According to Organization for Economic Cooperation and Development (OECD) data, Mexico has the lowest financial inclusion among its population (OECD, 2017); only one-third of the population has access to a savings account in the country, not to mention credit. According to estimates, only 6% of the population in Mixteca has knowledge or access to financial services (World Bank, 2019). The lack of financial education in rural areas is another aspect to consider, as people still believe that they do not need to learn to manage their limited budgets (Servín, 2018). Thus, inhabitants tend to favor informal ways to finance, such as community financial societies, cooperative loan societies and popular financial societies, which lack rigorous standards. Moreover, there are no official banking institutions in the area, except for one bank located in the most developed community. A specific condition in Mixteca (as well as for any other rural area in Mexico) for low financial inclusion is poor quality customer service (bad treatment) provided by the financial service entities due to low-income individual misconceptions and prejudices, and lack of financial education (CONAIF, 2018). Financial services are a limited activity; there are only two commercial bank branches, and 12 furniture and clothing sales financing retail business entities and pawnshops. Loans for productive activities are scarce and limited to small amounts (INEGI, 2021).

3.8 Legal system and community organization

The weak rule of law is present in Mixteca. For example, electoral manipulation and vote-buying are ubiquitous, in exchange for future benefits such as federal social programs. One in two people in Mexico was offered a bribe for their vote, and one in four was threatened with retaliation (Pring and Vrushi, 2019). The issue is exacerbated in Mixteca by factors such as the population's financial dependence and the association with low levels of schooling (Vilalta, 2010), which are well-known and widespread. In transgressions related to corruption, impunity reached 98% (Muno et al., 2019); simple acts such as a request for public services, among other interactions with the government, are actions that involve acts of corruption which are also experienced among the poorest communities (Rodriguez-Sanchez, 2018).

The society in Mixteca has inherited ancestral organizational practices of community service for collective projects called *Tequio* (from the native Náhuatl language: tribute or work). The practice generally means donating work, financial resources or an array of goods for community service activities. Beyond the organizational work-tribute structure, it is a moral duty that provides multiple contributions to individuals as well as to the collectivity (Tobón, 2017):

- sense of belonging to a community by stimulating inhabitants to organize and work for the collective benefit (avoids individuality);
- transcends with the transfer of knowledge between generations;
- challenges and decisions are taken within the community;
- recognition that individual participation contributes to the collective benefit, (a check-list is usually in place) hence responsibility is enforced;
- strengthens the organizational, interpersonal and communication skills among all members;

- every participant receives support in exchange for the work performed;
- entitlement to rights as well as to duties within the organizational process.

Figure 13. Community members taking part in 'Tequio' by building a civic center.

This type of organization also takes part in the local access to justice known as customary law and contributes to building local inclusive and accountable institutions for the development of the community. Customary law ("usos y costumbres" in the Spanish language) is the straightforward justice delivery choice in rural communities in Mixteca, especially given the perception that the rule of law is weak towards transgression. Justice is taken into the hands of the community members and radical solutions are usually exerted, i.e., physical punishment towards an offender (thief, kidnapper) to demotivate future transgressors (Díaz-Cayeros et al., 2014).

3.9 Ethnic transformation

From the mid-sixteenth century onward, Catholic church institutions asserted their control over the indigenous people in Mixteca. They used the labor of the indigenous people to build and subsequently maintain the religious structures in Mixteca - with European designs (Spores, 2018). Currently, the Catholic religion still plays an important cultural role in the region. Statistics show that around 91% of the population identifies themselves with Roman Catholic religious beliefs (INEGI, 2021). Church institutions also asserted their control over an ever-growing patrimony of agricultural, residential and industrial land. Although during the colonial period, a large number of new elements were introduced into Mixteca, the native culture and ideology were not eliminated. Many indigenous elements were integrated into the symbolism of Mixteca colonial religious institutions, and many others, such as the indigenous knowledge of cultivated plants, the system of terrace-irrigation, as well as the regional clothing, the indigenous agricultural system, native therapeutics, and several other institutions, techniques and items, have survived to the present day (Aguilar Sánchez, 2020).

Colonization meant a disturbance for the cultural heirs of Mixteca. This upheaval has meant that today's Mixteca descendants (they call themselves the *Ñuu Savi*, "people of the rain" or "children or descendants of the people of the rain" rather than Mixtecos (López Bárcenas, 2007)), generally referred to as "indigenous", have a widespread ignorance of their fragmented knowledge of their cultural-historical heritage, which ultimately translates into a loss of identity and a disadvantage in cross-cultural intercultural relations in a globalized world. The clearest reflection of this is the loss of language or loss of speakers of the native language. On the other hand, what we know of this past makes it difficult for the current Mixteca native population to identify themselves with the inherited labels, in addition to the discrimination that they are subjected to as descendants of "indigenous" communities in Mexico (Aguilar Sánchez, 2020).

Coming from a native group can also be seen as a factor of discriminatory argument, to the extent that speaking a native language provides a reason to be ashamed (Núñez Barboza, 2005). The government in the past decades has not enforced dissemination nor promotion of cultural diversity, and education has been forced to be in the most widely-spoken language in the country –Spanish - (INEE, 2019), hence the loss of indigenous language speakers. Thirty-one indigenous languages are recognized to be spoken in Mixteca, but only 5.55% of the population (around 14100 people) speak one of them (author's calculation per latest available data from (INAFED, 2010). Three are the main native languages spoken: Mixteco (which represents 34% of the total number of speakers of indigenous languages), Náhuatl (48% of speakers) and Popoloca (12%) (author's calculation per data from (INEGI, 2021)). The number of native speakers is decreasing, thus a loss of native culture is also vanishing. For the sake of comparison, records show that 61 indigenous languages are spoken throughout the state of Puebla, and Mixteca contributes to half of them.

Vendors in the market square in Mixteca, photo by the author.

Palm weaving women, photo from (López Bárcenas, 2007)

Figure 14. Traditional economic activities in Mixteca.

"Mixteca culture did not disappear with the Conquest, nor it did during the colonial period or the strong upheavals of the nineteenth and twentieth centuries; it exists today, it exists in Mixteca, in all parts of Mexico, and in any part of the world where the Mixtecas have arrived in their great diaspora of adaptation. Many have left Mixteca, but their hearts, their feelings and their thoughts are in their land and their tradition" (Spores, 2018).

"One of the most exciting opportunities created by renewable energy technologies like solar, is the ability to help the world's poorest develop faster - but more sustainably too"

— Edward J. Davey (2014)

4. Solar energy system overview

This chapter 4 along with previous chapters 2**Error! Reference source not found.** and 3 belongs to Part 2 of the dissertation; the case study presentation (see chapter 0).

The most abundant energy resource on Earth by far is solar energy, which is present over the entire surface of the Earth. The total annual solar radiation reaching the earth is more than 7500 times the world's total annual primary energy consumption of 450 exajoules (EJ). Around 0.1% of the energy reaching the surface of the earth when converted at an efficiency of 10% would generate four times the world's total generating capacity of about 3000 gigawatts (GW) (Thirugnanasambandam et al., 2010).

As a result of the direct and diffuse radiation, photovoltaics and solar thermal collection systems can be placed almost anywhere on the surface of the Earth to generate electricity and heat, respectively (GEA, 2012). However, it is important to note that specific techniques and technologies exist to maximize absorbed energy and minimize losses. Solar energy conversion technologies have the capability to provide electricity generation as well as a variety of energy services, including heating, cooling, and natural lighting. At present, there are mainly two technologies that directly contribute to the capture and application of solar energy to provide electricity, photovoltaic (PV) power generation and concentrating solar power (CSP) plants (IEA, 2019).

Several factors reduce the harvestable potential of the solar source, the main ones are daily and seasonal variations, geographic location and weather conditions. Regions close to the Equator generally receive more radiation than those at higher latitudes (IEA, 2020a). Atmospheric conditions have the greatest impact on solar energy availability. Solar tracking systems try to compensate for geographical challenges despite only being able to harvest direct sunlight, which is typically affected by weather conditions. As irradiation is often diffuse, large-scale generation of solar energy can carry significant land requirements (GEA, 2012). In addition to technical factors, social considerations can pose a challenge to energy harvesting, e.g., land use conflicts due to agriculture, public acceptance or "not in my backyard" constraints; protected areas, and topology also affect the installation of larger projects (IEA, 2020b).

The following paragraphs offer a review of the two main types of solar technology; CSP in section 4.1, and PV in section 4.2, with remarks on efficiency and capacity, which are important factors to evaluate suitability for the Mixteca region. Section 4.3 provides an overview of the capability Mixteca would have to contribute to solar energy generation; this section also synthesizes information about the present energy market in which Mixteca is immersed within the country. Section 4.4 analyzes the generation costs for solar energy in the local market, comparing between the two technologies, CSP and PV. Section 4.5 concludes the chapter with a critical analysis of both solar technologies with a probable adaptation to Mixteca, considering geographical, spatial, economic and social considerations.

4.1 Concentrating solar power plants

Concentrating solar power (CSP) systems work in areas with high direct normal irradiance (DNI) by concentrating the sun's rays using mirrors or lenses to produce heat. This heat is transferred to a heat transfer medium, typically a thermal oil or molten salt. Electricity is then generated through a thermodynamic cycle, for example using the heat transfer fluid to create steam and then generate electricity. Diffuse solar energy cannot be used, as it has no uniform direction. Heat loss means that for CSP systems to operate efficiently, they require a minimum input of direct sunlight. Suitable areas for a CSP plant installation, i.e., with high DNI, are usually found in arid and semi-arid areas, between 15° and 40° latitude, and at higher altitudes, where both the air density and scattering absorption are lower (IEA, 2010a).

CSP systems can be classified by the way they focus the sun's rays and the technology used to receive the sun's energy, according to the mechanism by which solar collectors concentrate solar irradiation and the arrangement of the concentrating mirrors: either "line focus" types - collectors which track the sun along a single axis and focus irradiance on a linear receiver to make tracking simpler-; or "point focus" types – where collectors track the sun along two axes and focus irradiance at a single point receiver, allowing for higher temperatures. In the following, a description of the current main CSP technology is presented (DLR, 2021; GEA, 2012; IEA, 2019, 2020a) and a graphical representation is shown in Figure 15.

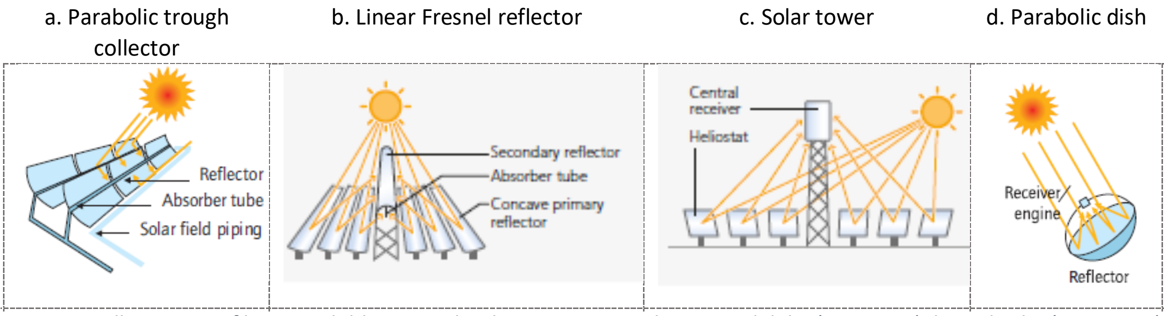


Figure 15. Illustration of best available CSP technology types. Graphics a. and d. by (IEA, 2019), b. and c. by (DLR, 2021)

- Parabolic trough collectors (PTC) consist of parallel rows of mirrors (reflectors) curved in one dimension to focus the sun's rays. The mirror arrays can be more than 100 m long with the curved surface 5 to 6 m across. Stainless steel pipes (absorber tubes) with a selective coating serve as the heat collectors. The coating is designed to allow pipes to absorb high levels of solar radiation while emitting very little infra-red radiation. The pipes are insulated in an evacuated glass envelope. The reflectors and the absorber tubes move in tandem with the sun as it crosses the sky. Parabolic troughs are the most mature of the CSP technologies and form the bulk of current commercial plants (IEA, 2019).
- Linear Fresnel reflectors (LFR) are another type of linear focus system, though less deployed. This system relies on an array of long rows of flat or slightly curved mirrors to reflect the sun's rays onto a downward-facing linear receiver above the mirror array. The receiver is not attached to the collectors, but situated in a fixed position several meters above the primary mirror field. The main advantage of LFR systems is that their simple design requires lower investment costs and facilitates direct steam generation, thereby eliminating the need for – and cost of – heat transfer fluids and heat exchangers. LFR plants are less efficient

than PTC in converting solar energy to electricity and it is more difficult to incorporate storage capacity into their design (DLR, 2021).

- Solar towers (ST), sometimes also known as central receiver systems (CRS), use hundreds or thousands of small reflectors called heliostats - a ground-based array of mirrors - arranged in a circular or semi-circular pattern to concentrate the sun's rays on a central receiver placed at the top of a large fixed receiver tower. Each heliostat is individually controlled to track the sun, orientating constantly on two axes to optimize the concentration of solar irradiation. The concentrating power of the tower concept achieves very high temperatures, thereby increasing the efficiency at which heat is converted into electricity and reducing the cost of thermal storage. In addition, the concept is highly flexible; designers can choose from a wide variety of heliostats, receivers, transfer fluids and power blocks. ST are the most widely deployed point focus CSP technology, but represented only around a fifth of the systems deployed at the end of 2020 (SolarPACES, 2021).
- Parabolic dishes concentrate the sun's rays at a focal point positioned above the center of the dish. The entire system tracks the sun: the dish and receiver. Most dishes have an independent generator at the focal point, thus eliminating the need for a heat transfer fluid and for cooling water. Dishes offer the highest solar-to-electric conversion performance of any CSP system but are limited in size (typically tens of kW or smaller) and each produces electricity independently, which means that hundreds or thousands of them would need to be installed to create a large-scale plant (IEA, 2019).

Table 1 gives an overview of some of the parameters related to the best available CSP technologies (IEA SolarPACES et al., 2016; Müller-Steinhagen, 2013). The values related to the parabolic trough collectors have been demonstrated in the field for some decades since it is the most mature technology. The aim is to improve conversion efficiency further. The higher efficiency of solar towers compared to PTC plants is due to the higher fluid temperatures (to over 1000 °C) which leads to better thermodynamic performance. In contrast, thermal oil in PTCs has a top temperature (about 400 °C) which limits the conversion efficiency of the turbine cycle. A new generation of these plants aims to improve the conversion efficiency. PTCs are commercially proven, they have better land-use factor compared to STs and the lowest material demands of this type of technology. Linear Fresnel reflectors have been operating at an early stage, and values are mostly based on pilot plants scale, but the use of direct steam generation promises relatively high conversion efficiency. LFR design uses less expensive reflector materials and absorber components, hence, LFR could become a low-cost alternative within CSP. The estimated life expectancy of a CSP plant is around 40 years, which is comparable to a standard power plant (IRENA, 2022). CSP plants are economically viable when operated as large-scale systems with nominal outputs, with a usual range from 50 to 200 MW (IEA, 2019).

Table 1. Performance data on best available CSP technologies. (IEA SolarPACES et al., 2016)

Technology	Capacity (MW)	Peak solar to electricity conversion efficiency (%)	Annual solar to electricity efficiency (%)	Land use (m^2/MWh)
Parabolic trough collector	5-280	23-27	15-16	6-8
Linear Fresnel reflector	10-200	18-22	8-10	4-6
Solar tower	10-150	25-35	17-25	8-12
Parabolic dish	0.01-0.4	20-30	20-25	8-12

4.2 Photovoltaic systems

Photovoltaic solar energy is the direct conversion of sunlight into electricity. The basic building block of a PV system is the solar module, which consists of a number of solar cells using semiconductors for the conversion. As these systems are able to exploit both direct and diffuse solar radiation, they are much more versatile in their application, and a much lower irradiance boundary determines their effectiveness. Their orientation still plays an important role in both centralized and decentralized applications, as they cannot track the sun. Centralized systems usually require large land space, whereas small-scale installations could be placed on a roof or at a stable spot (IEA, 2010b). Solar cells and modules vary greatly in performance and degree of maturity. Applications range from consumer products (milliwatts) and small-scale systems for rural use (tens or hundreds of watts), to building integrated systems (kilowatts) and large-scale power plants (megawatts up to gigawatts). Even though the technical potential of solar energy exceeds the current and estimated future worldwide energy use, there is no consensus on the economic potential of solar energy in general, and of PV in particular, because of the many technical, economic, and societal aspects at play (IEA, 2021).

Since PV is a highly modular technology and does not involve moving parts, it can be integrated into buildings (roofs and facades), and infrastructure objects such as noise barriers, railways, and roads, allowing for more energy output per surface area. This makes PV a suitable technology for use in rural, urban and industrial areas.

The market for PV systems can be divided into two main categories (IEA, 2022):

• Grid-connected PV systems – can be building-integrated and building-adapted systems (distributed systems), ground-based systems (power plants), and others (such as systems on sound barriers).

• Off-grid / stand-alone PV systems – can be solar cells integrated into consumer products, professional systems (e.g., telecom), rural PV systems, mini-grid systems, and others.

The market can also be divided according to the type of ownership, such as households, housing corporations, industries, companies, utilities, and institutional investors. PV is expanding rapidly due to effective supporting policies and cost reductions. PV is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. According to the IEA, 5% of the world's electricity generation in 2021 was covered by PV (IEA, 2022). In the IEA roadmap for the global energy sector, PV is projected to provide 12% of global electricity consumption in 2030, rising to 19% in 2050. It also estimates that solar energy will become the largest source, accounting for one-fifth of energy supplies. In addition, solar PV capacity would increase 20-fold between now and 2050. The electricity sector is also foreseen to be the first to achieve net-zero CO_2 equivalent emissions, mainly because of the low costs, widespread policy support, and the maturity of an array of renewable energy technologies. Solar PV is the cheapest new source of electricity in most markets and has policy support in more than 130 countries (IEA, 2021). The IEA roadmap envisions a rapid growth of PV energy throughout the world, but at a later stage in Latin America and Africa. Major economies like China and India have become global solar energy forces in the past decade, and will remain important market influencers in the decades to come. The potential of PV for distributed generation is substantial in Latin America and Africa. These world regions may become very important markets in the mid- to long-term.

With the aim of achieving further significant cost reductions and efficiency improvements, research and development is predicted to continuously progress in improving existing technologies and developing new ones. Commercial solar cells are usually wafer-based and made from crystalline or thin-film silicon, thin film cadmium telluride, copper-indium/gallium-diselenide/sulfide (CIGS) - see Figure 16 (ZSW, 2017), whose efficiencies are expected to increase from 6% (base year 2010) to 25% in 2030, with the potential of increasing up to 40% in 2050. In research, alternative forms of cells such as organic / inorganic, perovskite and hybrid materials are emerging technologies whose efficiency under controlled conditions have reached up to 47% (NREL, 2022a). A comparison chart showing the best research cell efficiencies can be seen in Figure 35 (Appendix B). At the same time, the use of energy and materials in the manufacturing process will become significantly more efficient, leading to considerably shortened PV system energy pay-back times (the time needed for the PV system to repay the energy spent in its manufacture). The operational lifetime is also expected to increase from 25 to 40 years (IEA, 2010b).

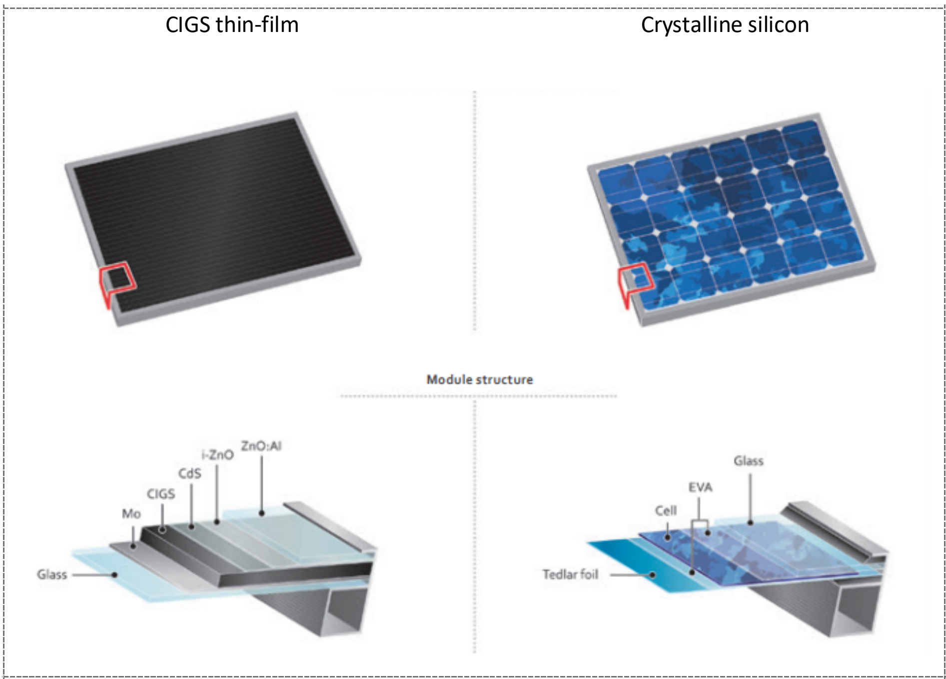
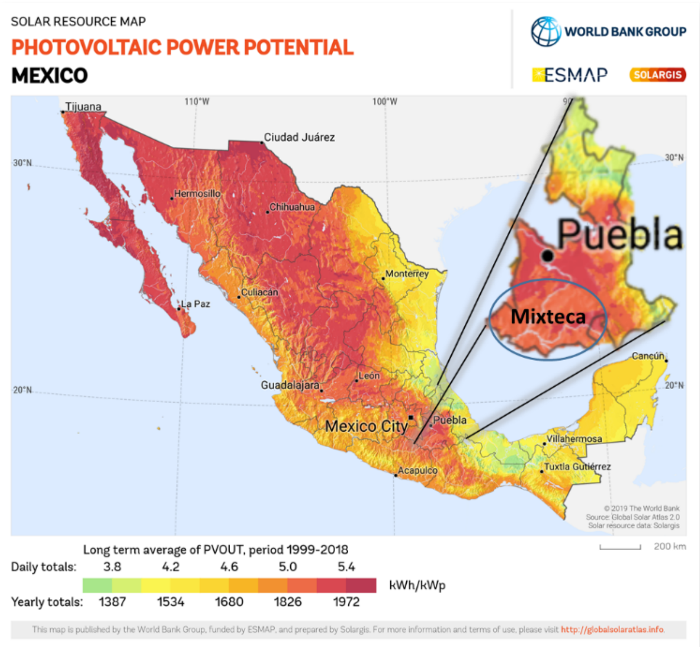


Figure 16. Illustration of the structure of PV modules. Graphics by (ZSW, 2017)

Efforts are needed to increase the number of qualified workers for a growing solar industry along the value chain and the lifecycle of PV product development, from research to system installation and maintenance. A well-trained workforce is necessary to ensure technology development, quality installations, cost reductions, and consumer confidence in the reliability of solar installations. These activities should focus on building the capacity of educational institutions to respond to the increased demand for high-quality training for solar system's installers. Governments are encouraged to provide training and education to create a skilled PV workforce along the full value chain. This involves developing outreach programs that target specific professional groups (e.g., local government planners, architects, home builders) (IRENA, 2022).

4.3 Solar energy status in Mixteca

The spatial location of Mixteca as well as the temperature, altitude and landscape described in Chapter 0 contribute to the country's high irradiation levels. The values recorded in Mixteca are higher than within the state of Puebla overall. Figure 17 shows the solar PV power potential in the region. As can be seen, Mixteca's potential is as high as north Mexico where the highest solar irradiation levels take place. Mixteca's values register above 6 kWh/m^2 solar radiation (Solargis -World Bank Group-, 2022), and values as high as 6.4 kWh/m^2 have been reported (Jonathan, 2012). Considering this potential and the trend of sinking costs of solar energy generation, Mixteca could have a considerable opportunity to take part of the solar energy generation share, not only in the region, but to participate in the state and national generation share.



Map data (min-max range)

Specific photovoltaic power output	PVOUT	5.04	–	5.25	kWh/kWp
Direct normal irradiation	DNI	5.99	–	6.74	kWh/m^2
Global horizontal irradiation	GHI	6.12	–	6.38	kWh/m^2
Diffuse horizontal irradiation	DIF	1.79	–	2.06	kWh/m^2
Global tilted irradiation	GTI	6.48	–	6.76	kWh/m^2
Optimum tilt of PV modules	OPTA	20	–	22	°
Air temperature	TEMP	18.5	–	26.0	°C
Terrain elevation	ELE	704	–	2550	m

Figure 17. Solar PV potential in Mixteca-Puebla, Mexico. Map and data from (Solargis -World Bank Group-, 2022)

The country's present legal, regulatory, and energy market frameworks have created significant barriers to market entry. Mexico's current government has redirected the energy sector by strengthening and favoring state-owned energy and electricity suppliers - PEMEX and CFE - over the private sector (Deign, 2020). The present administration seems also to backstep on the committed climate goals, causing uncertainty for private investors who are the main drivers of clean energy production. New solar energy developments have been paused, and new permits are no longer granted (Flannery, 2021b). Nevertheless, one scheme that Mixteca can take part in and benefit from, despite the country's restrictions, is the decentralized solar systems.

Decentralized solar systems - also called distributed generation - are small-scale, self-supply solar energy systems. According to the country's energy transition law and electric industry law, electricity generated from distributed generation should not exceed a capacity of 500 kilowatts (kW) and must be connected to the distribution grid. These solar generators do not need a governmental permit for installation (SENER, 2016-2020). These small-scale solar systems were initially established in rural areas that were not connected to the national grid. Therefore, Mixteca can make use of this scheme to take advantage of its solar potential and profit from it. If additional rural areas like Mixteca take part in this mechanism, distributed generation could be expected to play an important role in the country's energy mix in the future (ASOLMEX, 2021) as cited in (Posma, 2020).

Though distributed solar generation is still in an emergent stage in Mexico, it has witnessed rapid growth in the last few years. One of the major factors driving the growth of distributed solar generation is the reduction in the cost of solar PV systems. As of March 2022, average solar energy systems in Mexico cost USD 3.07 per watt (Mexico Energy Partners LLC, 2022), which is expected to reduce further with technological development and the inflow of solar panels from various countries.

Puebla is one of the 13 states (out of 32) in the country with an electricity deficit, where more than 20% of electricity is supplied from other states due to the disproportion between demand and electricity generation. The state is also the region with the fourth-highest prices. In addition, 39 of Puebla's inhabited localities are not electrified, 30 localities out of 472 are partially electrified and 69 localities with a population of approximately 1500 inhabitants do not have access to electricity services (Gobierno de Puebla, 2019a), many of them located within Mixteca. According to its "Sustainable energy development plan" (Gobierno de Puebla, 2019b), Puebla faces the challenge of reducing the outsource of electricity. This is possible with the growth and development of electricity infrastructure through the agreement between the Federal Government, the state and the municipalities, together with strategic planning that incorporates the private sector as part of the approach to guarantee the population's access to energy services. Mixteca could fit within the state's plan and participate in this electricity generation goal from solar PV systems, if it is successfully implemented.

Research studies have produced scenarios for the short-term future for Puebla state (NREL, 2022b). In addition to the "business as usual" scenario, two more were produced, one with higher renewable energy penetration, named Accumulated Renewable Energy (ARE), and another with even greater renewable energy penetration (ARE+). For the state of Puebla, the accumulated renewable energy deployment scenario (ARE) foresees utility scale capacity of 700 MW of solar projects that are in more "advanced stages of obtaining permits, financing, interconnection or beginning construction".. In the most ambitious scenario, ARE+ foresees utility scale capacity of 1610 MW where projects are in "less advanced stages of permitting and obtaining financing and interconnection". The "business as usual" scenario, given the current governmental policy uncertainties and the challenges of the country's energy sector, remains as of year 2020 in which a 200 MW capacity solar PV power plant started operations. This solar PV plant is located 200 km north of Mixteca (SENER, 2021). Under these circumstances, and as Figure 17 shows, solar PV potential in both the state of Puebla and in Mixteca remains undervalued and unexploited.

4.4 Solar energy generation costs

Due to lack of solar projects in Mixteca and scarce available data for the state of Puebla, reference information for this research needed to be provided from national sources. Projects with competitive costs in Mexico have led to weighted-average total installed costs of USD 866/kW in 2020, a value 21% lower than in the USA, and a decline of about 52% between 2015 and 2020 (author's calculation per data from (IRENA, 2021; ProMexico, 2017; SENER, 2021). Solar PV total installed cost reductions are related to various factors. The key drivers of lower module costs are the optimization of manufacturing processes, reduced labor costs and enhanced module efficiency. Furthermore, as project developers gain more experience and supply chain structures continue to develop in more and more markets, declining costs have followed. This has led to an increased number of markets where PV systems are achieving competitive cost structures and falling global weighted average total installed costs.

In contrast, the capital costs for CSP projects ranged between nearly USD 4300/kW and USD 5200/kW for a storage level range from 8 to 12 hours. These figures are related to LFR and PTC. Solar tower cost data is more spread out, ranging from nearly USD 4000/kW to 7000/kW, most STs with no or less storage capacity - range from 4 to 8 hours. Total installed costs for CSP plants fell by 50% between 2010 and 2020 (author's calculation per data from (IRENA, 2021; ProMexico, 2017; SENER, 2021). Figure 18 shows the comparison between the PV and CSP technologies on installation costs.

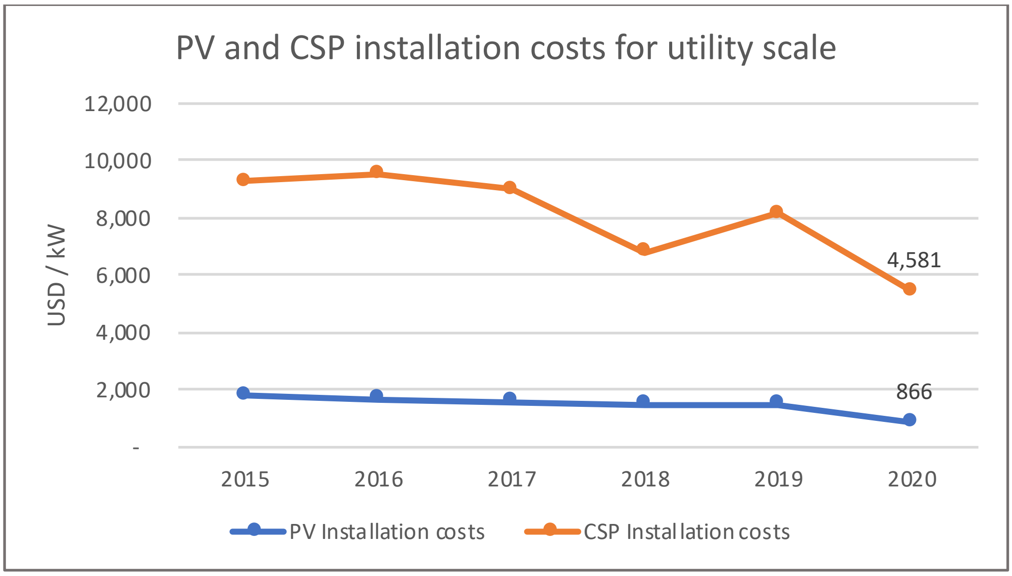


Figure 18. Installation costs for solar technology in the Mexican market

The operation and maintenance (O&M) costs of utility-scale solar PV plants have declined in recent years, driven by module efficiency improvements. For 2020, the solar PV calculations assume utility-scale O&M costs of USD 17.8/kW per year for projects commissioned in the OECD member countries (a 3% decline from 2019) (IRENA, 2021).

The global weighted-average levelized cost of electricity (LCOE)[2] of utility-scale PV plants declined by 85% between 2010 and 2020, from USD 0.381/kWh to USD 0.057/kWh (EIA, 2022).

[2] The LCOE represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle (EIA, 2022).

The rapid decline in total installed costs, increasing capacity factors and falling O&M costs have contributed to the remarkable reduction in the cost of electricity from solar PV and the improvement of its economic competitiveness.

Likewise, the weighted-average LCOE of CSP plants also saw a decrease, by 68% between 2010 and 2020, from USD 0.34/kWh to USD 0.108/kWh. This was primarily driven by reductions in total installed costs, higher capacity factors (around 30-40%), the assumed reduction in the weighted-average cost of capital, and lower O&M costs (IEA, 2020a; IRENA, 2021). For CSP plants, O&M costs are usually higher compared to solar PV and vary depending on location, irradiation, design, technology used and local conditions. Traditionally, the most significant O&M cost has been the receiver and mirror replacements expenditure; new technology, improved designs and qualified labor have contributed to decreasing the costs. An accepted range between 0.5% and 1% of the initial capital outlay constitute the current O&M costs of a CSP plant (IEA, 2021). An estimated O&M cost for the Mexican market provided by IRENA provides an even lower cost range of USD 0.016 and 0.015 kWh for PTCs and STs respectively (IRENA, 2021), despite the fact that Mexico has not yet installed any of these technologies.

A comparative chart in Figure 19 shows the LCOE evolution in the last decade. Even though the displayed data apply to the costs published by (IRENA, 2021) for the global market, Mexican governmental sources have in the past cited the same source as a reference for the internal market (SENER, 2018). Current information for the local market is either not updated or not displayed (see (SENER, 2021)) and further historical data is not available, see (CENACE, 2022), (CRE, 2022), (CFE, 2022), hence a comparison within the internal market could not be performed. Since CSP technology has not been installed in Mexico and PV projects for utility scale have been put on hold (Bellini and Zarco, 2020; Flannery, 2021b; O'Sullivan, 2022), the comparative Figure 19 is used as a reference for future outlook on solar LCOE price decrease.

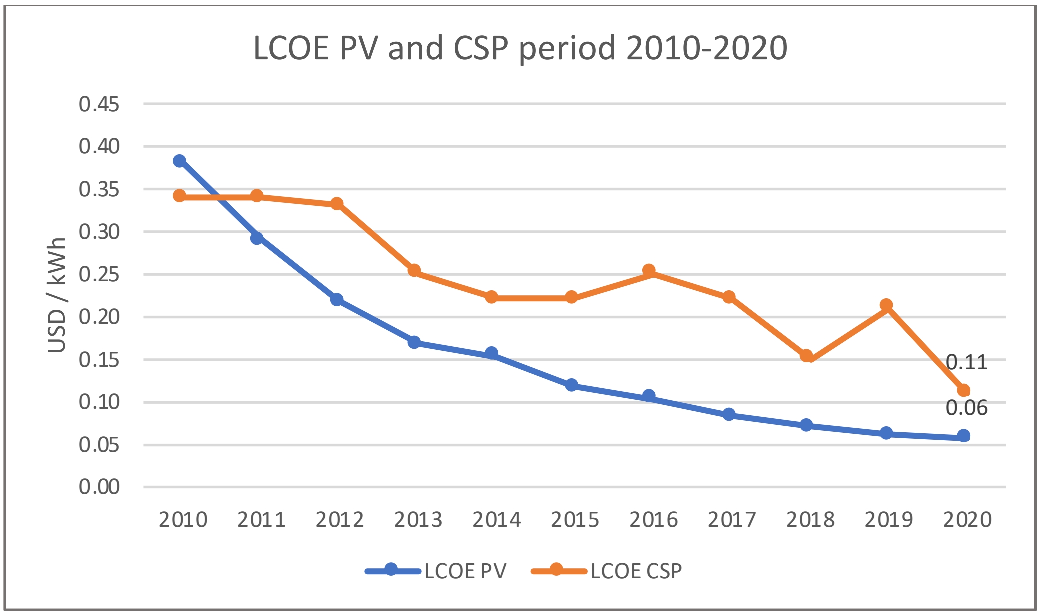


Figure 19. LCOE global evolution from 2010 to 2020 for solar technologies.

Public installation prices of distributed generation systems in the Mexican market vary according to their power range, the lower capacity (up to 5 kWp installed capacity) is more expensive (USD 1.24/Wp) than the highest capacity allowed for this type of system: 250-500 kWp at a price of USD 0.85/Wp (ASOLMEX, 2021). Regarding the price per component (modules, inverters, accessories, labor, inspection, etc.), wholesale prices favor lower prices per component in distributed generation systems with higher installed capacity, and total prices range from 1.48 to 1.01 USD/Wp (author's calculation from data from (ASOLMEX, 2021)).

Figure 20 shows the cost breakdown for PV distributed generation systems that would suit Mixteca's conditions. As seen, the component costs correspond to the highest share of the cost, followed by the installation costs. In the components section, the hardware share which is mainly driven by the PV solar panels, composes the main part of the components' cost share (50%), followed by the inverter (20%), racking and mounting (20%), cabling and wiring (10%) (author's calculation from data from (ASOLMEX, 2021)). Soft costs account for the financing, system design, permitting and inspection, incentives and profit margin.

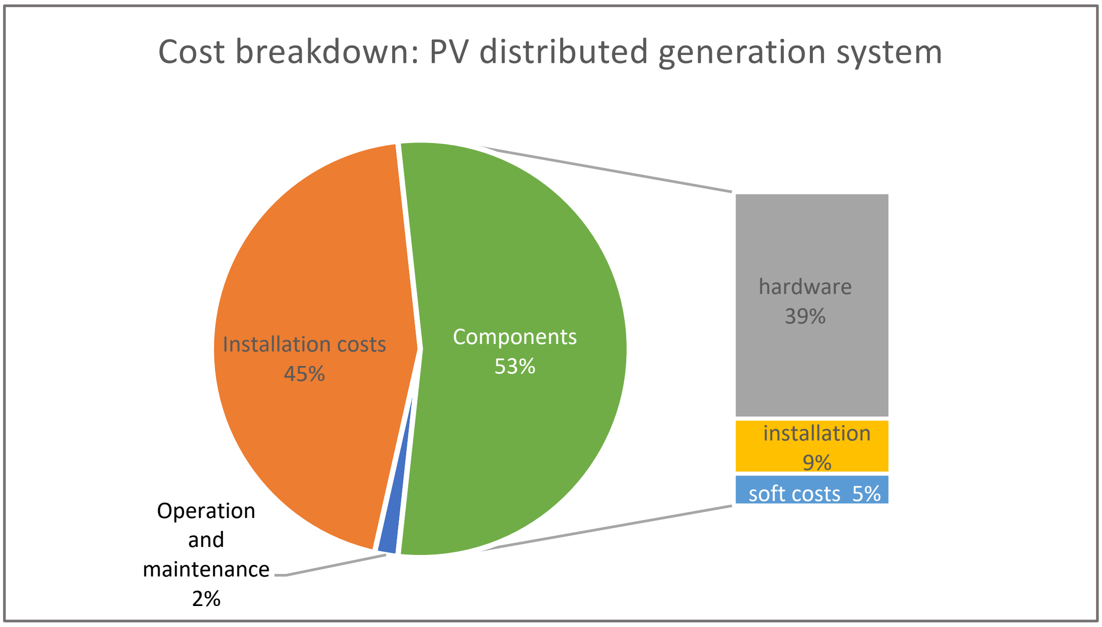


Figure 20. PV cost breakdown for distributed generation in the Mexican market.

The most installed system capacity consisted between 1 to 30 kW which represented 65% of the total accumulated capacity of distributed generation in Mexico during 2020. These interconnection contracts were related mostly to installations that took place on roofs (nearly 60% of the cases), in metal structures (around 30%), or on flat land (5%) (ASOLMEX, 2021).

Table 2 summarizes the installation costs, operation and maintenance, and provides a calculation of the LCOE for Mixteca under the conditions of the Mexican market (author's calculation per information from (IRENA, 2021) related to the Mexican market and latest information available from (SENER, 2021)). Despite sinking costs for CSP technologies, PV costs have also decreased. Future outlooks foresee that they could still be a cheaper alternative for solar energy.

Table 2. Solar technologies - costs under Mexican conditions.

Concept	CSP	PV
Installation costs (USD/kW)	6,607	866
Operation and maintenance (USD/kW per year*)	48.60	17.80
LCOE (USD/kWh)	0.129	0.093

*Total fixed annuity costs (IRENA, 2021) calculated through (Walker et al., 2020) with methodology by (Castillo-Ramírez et al., 2017)

4.5 Prospects for Mixteca

Following the technology analysis in sections 4.1 and 4.2, both CSP and PV can be seen to have a high potential to contribute to Mixteca's energy transition. They could thus add to the renewable sources share and the decarbonization of the energy system, in addition to bringing societal advantages that would facilitate the regions sustainable development (Chapters 0 and 0). The following paragraphs provide a comparative analysis between the feasibility to adapt each technology to the local conditions in Mixteca; the chapter concludes with the selection of the most suitable solar technology for the area.

From the technological point of view, both systems CSP and PV are suitable for the irradiance conditions in Mixteca (see Figure 17), where geographic location and meteorological conditions, such as high altitude and air density, allow their deployment (see section 3.1). But despite Mixteca's excellent irradiation levels, its spatial location would not allow the implementation of a large-scale system (either CSP or PV) due to its mountainous terrain (see chapter 0).

Sections 4.1 and 4.4 showed that CSP plants are economically viable when operated as large-scale systems, whose lowest output starts at 10 MW (see Table 1) even though the widespread minimum installed capacity is 50 MW. Smaller systems at locations with good solar radiation could be economically feasible if the capability to process heat can take place (DLR, 2021). In contrast, PV is not subjected to a minimum installed capacity, due to its modularity and size flexibility, PV systems do not depend on their size to be efficient and economically viable; they can be scaled as small as desired, and can be deployed as small as necessary depending on local demand, and grow in time (see section 4.2).

In addition to the technology per se, adequate infrastructure in the area is another pivotal criterion to consider before deployment. In order to build a utility scale plant (either CSP or PV), access to transportation routes is needed. In addition, a functional electricity grid network (high or medium voltage) is also required. In Mixteca, new electricity transmission and distribution infrastructure is required, since the one currently available does not comply with present demand, and will not be able to support additional energy generation (see section 3.5). These infrastructure additions will also have an impact on the cost of the solar energy deployment and would need to be accounted for. Besides financial investment, time and governmental permits would also be needed to fulfill these requirements. In rural regions such as Mixteca with a weak economic structure, access to basic services is a consideration prior to technology deployment. Water supply in the region would also be required for the proper solar systems functionality. But this is currently not an assured service in Mixteca (see section 3.5).

Mixteca is a region prone to earthquakes (see section 3.2). Seismic activity is an unpredictable natural phenomenon that impacts directly on the costs of energy systems; in order to prevent damages in the solar technology structures, additional considerations (and costs) should be determined in the design. Potential damage should also be taken into consideration and risk assessments would also be needed. Another natural phenomenon that might influence the functioning of either solar system (CSP or PV) is volcanic eruption (see section 3.2). Mixteca lies around 77 km from the most active volcano near to the region, Popocatépetl. Even though the government does not consider Mixteca at risk if a volcanic eruption took place (see section 3.2) (CENAPRED, 2022), it cannot be disregarded that volcanic debris could reach the region, since it has been documented that lahars could flow as far as 100 km from the source (Thouret et al., 2020). Moreover, research shows that the volcano Popocatépetl has an increased probability to collapse (debris avalanche and debris flow) in the future due to its magmatic activity. The potential hazard of eruption increases when it is triggered by earthquakes (Capra et al., 2002). As a consequence, even if there is no major damage to a PV or CSP plant, ash rain might cover the mirrors or the PV panels; in addition, in the case of the CSP technology, it could block the mobile parts of the system. The clean-up process should be considered, which in the case of CSP would require a more detailed or a specialist check to make sure the system still works.

A CSP plant needs large land extensions, mainly for the installation of the solar mirrors. For instance, a 50 MW PTC needs an area of 195 hectares - most of this is used for the collector fields but also free space is needed for safety distances or shadow lengths (Schlaich Bergermann Partner, 2022). A relevant aspect for CSP installation is that the surface should be as flat as possible. Mixteca has large extensions of land with no productive use, which are not useful for agriculture, and are basically unused (see chapter 0). Nevertheless, its topographic characteristics, surrounded by hills, mountains and scarce flat surfaces are an important exclusion criterion for CSP deployment. On the other hand, if a PV system is installed on roofs or other already existing constructions, no additional space is required, allowing for more energy output per surface area.

CSP plants are major projects that require engineering, procurement and construction expertise that only a few large companies worldwide have the qualification to offer. In addition, the specific components and systems must also be planned and ordered under specialist knowledge (Hümmer, 2020), as cited and translated in (DLR, 2021). Operation and maintenance are also stages whose integration into the system require a high degree of control in order to operate appropriately. The specialized subsystems, machinery, components, connecting elements, cables and pipelines of a CSP system are far more complicated than PV systems. The quality of the optical systems has a significant influence on electricity production and thus on the profitability of a power plant. For this reason, specialist companies use dedicated measurement technologies for quality assurance and construction supervision (DLR, 2021). Nevertheless, it would be possible to use local companies and labor from the Mixteca region for the non-specialized construction work, so local added value could be possible. The operation of a CSP plant is also complex and places high demands on the working operators. For this reason, high capacity-building would need to be implemented in Mixteca to fulfill the labor requirements. It would be highly likely that trained employees would have to come from outside the rural area to start the operation of the plant, while the suitable degree of training can be attained within the labor force in Mixteca. High-level training reduces operating errors and ensures that the power plant workers learn to recognize possible system malfunctions at an early stage.

In contrast, a utility-scale PV plant is a more matured technology in the Mexican market (Mixteca and the state Puebla currently do not have large-scale plants), whose deployment in past years has proved an advantage compared to CSP (SENER, 2021). Construction, operation and maintenance of a PV plant have proved to be less elaborate and complex than for CSP, and local labor can be trained and used along all stages of the process (IEA SolarPACES et al., 2016). Local added value from Mixteca could occur throughout the process once capacity-building is achieved. Requirements for most processes are more adaptable to a lesser-skilled workforce than CSP plants. Nevertheless, in cases where the plant operators needed digital automated monitoring systems (for either type of technology), this sophisticated level of control could not be attained at the moment in Mixteca. In addition, the infrastructure level for digitalization is lacking in the area. A requirement would be the ability to count on the reliability of services to cope with the needs of the plant.

Compared to photovoltaics, a large part of the CSP added value, as well as the technological risk, arises during the adaptation of the components and their integration into a functioning overall system. In the case where a CSP plant could be installed, (setting aside the geographic challenges) the investors, contractors, as well as the operational teams, would mostly come from outside Mixteca, - only a minor and temporary proportion would be from the local population during the construction work. The added value in a case where a CSP plant could be deployed will likely not be distributed in the area, but in contrast, a utility scale PV installation is more likely to have added value distributed within the local population.

The installation of a CSP plant in Mixteca, considering its weak economic structure, would necessarily involve the improvement - or creation - of larger infrastructure projects, such as transport routes and the energy and water supply, than for a PV plant. The population in the region could be benefited by this improvement. The requirement for skilled people would bring workflows from outside Mixteca, and in addition, the region could become more attractive for the relocation of other companies. While it is true that the general economic situation in the region could improve, the most vulnerable part of the population might not benefit, at least not in the first years. Moreover, the change in the landscape, the unavoidable “urbanization” level the rural communities would reach, and the flow of outsiders, are factors that might make the native population feel threatened; the fear of losing their land, and the fear of alteration in the landscape could undermine their native culture.

Unfortunately, there is no reference point within Mexico to compare or identify conditions that would be useful for further analysis on the consequences of a CSP plant deployment, since Mexico has not yet ventured the installation of one. Several factors in addition to the investment and economic costs involved could be constraints, including the societal impacts.

Given the high initial investment cost of a CSP plant (see section 4.4) compared to a PV installation, it would be necessary that stakeholders outside Mixteca invest in the region. Consequently, factors such as investment risks, adequate financing, tax incentives and other conditions for investors are decisive. Long-term solar power purchase agreements are a way to secure contracts, while stability in the political and economic spheres are also valued among investors as guarantees of return on their capital. During project development, the planning and construction of large-scale plants such as CSPs requires a strong economic background to be able to pre-finance these activities, which run over several years. Under the current administration in Mexico, the energy landscape has encountered legal setbacks which have undermined investors’ confidence. Large projects have been stopped and legal plaintiffs have to withstand in court proceedings (O'Sullivan, 2022) against government's decision to cancel utility projects under construction.

From the initial investment costs, a CSP system represents a higher investment than a PV system, which is very likely not possible to be covered by the population in the area, whose access to loans are rather limited or non-existent. The owners (investors) of the energy system would follow the traditional producer-consumer model in which the income and profit go to the investors, and the population would hardly see any economic-social benefit, except for the solar energy production.

From the societal side, people would benefit from a stable electricity service provided by solar sources, but from the population's perspective, the main change would be the service provider. Given the high poverty levels in the area, a big share of the population will still be unable to pay for the electricity, regardless of the source or service provider. The question of whether the electricity price could be cheaper depends on the governmental agreements with the investors. But in a poverty-ridden rural region such as Mixteca where 75% of the population are income-deprived (see chapter 0) and almost one-fifth live under extreme poverty, it is highly unlikely that the most vulnerable population could benefit from the solar electricity provision that a utility scale plant could bring at the moment. Mixteca would not only continue to be energy poor but multidimensionally poor too.

In contrast, the flexible scalability and modularity of PV systems are more suitable for the topographic conditions in Mixteca. Moreover, given the sinking costs of the technology, a PV system would be feasible to be self-financed, either through cooperatives or a group of organized inhabitants. In addition, local ownership of energy production is recognized as a way of added value creation and distribution within the local economy (Whitaker, 1980; Ostrom, 1996; Brandsen et al., 2018; Miller et al., 2018), favoring wealth distribution among the inhabitants rather than the traditional focus of maximum economic profit for the energy system's owners.

Table 3 shows a comparative summary of CSP and solar PV technologies for Mixteca conditions.

Table 3. Comparative summary of CSP and solar PV systems adapted to Mixteca. Author's calculation, based on (SENER, 2021; IRENA, 2021; Kistenmacher, 2019).

Concept	CSP system	PV system
Initial costs (USD/kW)	6,600	870
Operation and maintenance (USD/kWyear)	48.60	17.80
LCOE (USD/kWh)	0.129	0.093
Lifespan (years)	30-40	20-25
Type of storage	Thermal	Batteries
Land use (m^2/MW)	40,469	31,160
Minimal power	10 MW	No minimal power required
Heat dependence	No	Yes
Irradiation needed	Direct Radiation	Global Radiation
Adaptability	Low	High
Qualified labor requirements	High	Low
Environmental impact	Low	Low
Establishment in the country	None	Widespread

This analysis was performed considering the installation of utility scale systems in the area. For utility scale, storage capacity is needed given the considerable amount of electricity that could be generated and not necessarily uploaded to the grid. Such an amount would exceed the threshold limit for distributed generation and so storage would be needed.

In order to reach a better understanding of electricity consumption in households in Mixteca, a series of interviews were held in five communities during a field trip in July-August 2019 (see chapter 0) to collect data on their present needs that could be useful to forecast consumption for the next decades. A summary of the calculations made for the data collected is presented in Table 4 (author's data collection, calculated and presented through (Kistenmacher, 2019)).

Table 4. Electricity consumption estimation for a household in Mixteca. Author's data collection, calculated and presented through (Kistenmacher, 2019).

Device	Consumption (kWh/day)
Refrigerator [a]	1.7
TV [b]	0.5
Lighting [c]	0.8
Radio [d]	0.3
Washing machine [e]	0.5
TOTAL	3.8
Safe value [f]	**4.0**

Some considerations on the calculation of the devices' consumption are as follows: [a] The refrigerator is estimated to be plugged 24 h/day, all year round running on a low efficiency mode; [b] A four-hour use per day and 20 hours stand by (a big model was estimated given the preferences of the people in the area); [c] Four light bulbs at 50 W for 4 hours a day; [d] Six hours a day, 50 W Radio; [e] Average washing machine with one run per day without any heating; [f] A tolerance was added to the calculations due to different consumption patterns. Refrigerator and washing machine devices were considered for future consumption since current household situation do now allow most families to own or use one. Additional information is presented in (Kistenmacher, 2019).

The electricity requirement of households is important for system design. For the calculated consumption of 4 kWh/day in Mixteca, a solar PV system design of one kWp would be a good start to cover basic current and forecasted initial needs in the area. This value corresponds to a module size of approximately 7 m² that could be installed within each household's ground area. A village with a population of 500 inhabitants would need about 2 000 kWh per day, which leads to considering a 0.4 MW of solar PV system of installed capacity (Kistenmacher, 2019). This amount is below the 500-kW threshold regulated by the government, so the distributed generation regulations could be applied. Due to the relatively small size of a single module, the modules could be installed and spread out in different places around the village, such as the local government offices' roofs, civic center, local market, schools or any other stable building's rooftop.

The scalability is a practical condition which would allow growth and a better distribution of benefits, and allow time for future investments. PV systems are also easier to maintain than a CSP and less expensive. For Mixteca, a rural area where people have low skills, a technology with low job requirements (such as PV) is likely to provide more employment benefits to the local community than high-skilled jobs, where workers are more likely to come from outside the region.

The greater the need for low-skilled workers, the greater the positive impact on the community, with job opportunities for the unemployed (Lambert and Silva, 2012). The current big solar projects on hold due to the current administration's drawback on environmental policies would not affect small self-producers like inhabitants in Mixteca. Poor communities would acquire empowerment, and independence from fossil fuels, despite the forbidding policies, and this would bring a better quality of life and general wellbeing. Solar PV systems seem to adapt better to the socio-economic-political conditions in the area. Conditions under which this system could be implemented will be analyzed in the following chapters 0, 0 and 0.

The Mixteca region shows a high solar radiation, and thus good conditions for solar power plants. However, currently the Mexican state has decided to support the fossil fuel infrastructure at the expense of current and future renewable energy investment (Tornel et al., 2019; Viscidi et al., 2020). This includes the construction of a new oil refinery and a new budget allocation to the modernization of coal-, diesel-, gas- and oil-fueled power plants. The decision to favor fossil fuel generation over renewable energy now positions Mexico on a path that hinders renewable energy generation, setting projects under development at risk. This decision could limit Mixteca's future plans to support renewable energy projects under utility scale systems, thus restricting its future development in clean energy (Bellini and Zarco, 2020).

"A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over with a working simple system"

— John Gall (1975)

5. Introducing 'Scenario-based Sustainability Assessment'

In order to have a better understanding of the proposed integration of the two approaches used throughout this research for the *Scenario-based Sustainability Assessment*, an explanation of each one is necessary. Thus, section 5.1 explains the Integrative Concept of Sustainability (ICoS) and its goals, followed by its framework conditions as described through its instrumental rules. Section 5.2 focuses on Cross-Impact Balance analysis (CIB). Section 5.3 elaborates on the proposed integration of both approaches as used in this research. This chapter conforms Part 3 of the dissertation related to the theoretical approach used in the study (see chapter 0).

5.1 Integrative Concept of Sustainability

An overview of sustainability assessment was provided in chapter 2, where it was generically defined as the process aimed at operationalizing sustainable development through the identification of potential future impacts as a decision-making strategy. At the end of section 2.2.1, an approach to sustainability assessment was briefly introduced. This chapter is devoted to explaining its competencies.

5.1.1 Substantial rules

The Integrative Concept of Sustainability (ICoS) was developed within the research centers of the Helmholtz Association. It has developed a normative set of criteria to allow empirical estimation or "measurement" of sustainability by fulfilling three criteria: a) *a clear object relation* in which it should be clear what the criteria apply to and what they do not; b*) the power of differentiation*: a concrete and clear designation of "sustainable" and "non or less sustainable" should be possible, as well as to assign such differences to societal circumstances beyond arbitrariness; c) *the possibility to operationalize*: it has to be considerable enough to allow sustainable indicators, to determine target values for them and perform practical measurements of sustainability on them (Kopfmüller, 2011).

The elements of ICoS (Kopfmüller et al., 2001) are grounded in three identified features of sustainable development, based on the World Commission on Environment and Development (Brundtland and Khalid, 1987), the 1992 UN Conference on Environment and Development in Rio de Janeiro, and several other scientific types of research and debatethe following elements:

- **The global perspective:** aiming to set concrete goals (targets) contextualized to the regional stance, as well as action strategies (proposals) considering the global mindset in the foreground, in which an appropriate interdependence linkage between the global and local levels exists.

- **The integrative position of the inter- and intragenerational justice postulate**: the concept of sustainability is linked to a vision of the future that grants future generations the same opportunities for life and development as the present generation; its implementation involves the recognition of rights and obligations between generations and in relations within each generation.
- **The relationship between humankind and the environment** in which humans hold the responsibility and obligation to preserve the existing diversity of possibilities of human interaction with the environment for future generations.

These three elements are introduced in two steps. The first step is related to the foundation of three general goals: *Securing human existence*, *Maintaining society's productive potential*, and *Preserving society's options for development and action*.

In the second step, the three goals are implemented through sustainability principles, which are applied to diverse social areas or selected features of the society-nature relationship. ICoS discerns between the minimum requirements for sustainable development to be assured for everyone in the current or next generations, called '*substantial principles*' (the 'what'-rules), and those principles that provide the required institutional, political and economic framework conditions to make the substantial conditions work, named '*instrumental principles*' (the 'how'-rules). The principles of sustainability form a normative aspect that provides guidance for future sustainable action; and also provide the criteria for assessing the degree of sustainability of a given aspect of society, policy or technological performance.

The structure of the three goals and their principles is summarized in Table 5 below (Kopfmüller et al., 2001) as cited and translated in (Grunwald, 2012).

Table 5. ICoS three main goals of sustainable development and their substantial rules

1. Securing human existence	2. Maintaining society´s productive potentials	3. Preserving society´s options for development and action
1.1 Protection of human health	2.1 Sustainable use of renewable resources	3.1 Equal access for all people to information, education, occupation
1.2 Ensuring satisfaction of basic needs	2.2 Sustainable use of non-renewable resources	3.2 Participation in societal decision-making processes
1.3 Autonomous subsistence based on income from own work	2.3 Sustainable use of the environment as a sink for waste and emissions	3.3 Conservation of cultural heritage and cultural diversity
1.4 Just distribution of access to natural resources	2.4 Avoiding technical risks with potentially catastrophic impacts	3.4 Conservation of the cultural function of nature
1.5 Reduction of extreme income or wealth inequalities	2.5 Sustainable development of man-made, human and knowledge capital	3.5 Conservation of social re-sources (tolerance, solidarity...)

The rules are intended to serve both as a guideline for the further operationalization of the ICoS concept, and as test criteria that can be used to identify sustainable and unsustainable conditions in the different regions they are applied. The rules have been designed to be observed as a whole, i.e., it is assumed that the rules can in principle be fulfilled simultaneously and can only be valid within the boundaries of the others, where the main focus may not be disregarded. For example, '*ensuring satisfaction of basic needs*' can be interpreted in different degrees of satisfaction depending on the socio-economic context, even between countries; nevertheless, in a poor and isolated region, the essential focus would be to gain access to basic services to minimally guarantee survival of all members of the community. Some potential for conflict between the objectives should not be denied, for example, survival of a rural impoverished community which needs its basic needs met may contravene ecological sustainability by depleting water and natural resources; hence, in principle, sustainability would no longer be guaranteed.

Particular interest is related to optimal fulfillment of the rules. The sustainability analyses require compilation of strategies and measures, which need to be extended to all dimensions of sustainability, not only for individual dimensions but across all of them; within the ICoS method this is called the 'integration of dimensions'. Priorities among rules or relevance considerations could be determined and are unavoidable once the rules are adapted to the particular context. Nevertheless, as a concept, ICoS introduces a theoretical multi-level foundation with clearly defined and non-arbitrary fundaments for sustainability. Weights or specific relevance are not assigned to any rule as a whole, but these can be determined at the contextualization level. Weighting helps to determine solutions and areas of fulfillment, as well as areas of trade-offs. Characterizations of the areas of fulfillment by weighting are constitutive for considerations. Hence, determination of weighting at the operationalization level is important. It should be noted that not all rules are applicable or relevant to the context-specific situation, nevertheless, the balance of general relevance among the three main goals of sustainability should be maintained (the weighting consistency rule); hence, the significance of the three main goals should be treated equally (Kopfmüller et al., 2001).

The ICoS rules have been applied to sustainability assessment in different circumstances and backgrounds, including energy cases (Rösch et al., 2018), urbanization (Kopfmüller, 2011), waste management (Fuss et al., 2018), sports and physical activity (Wäsche et al., 2021), the water-energy nexus (Friedrich, 2020; Steiner et al., 2018).

Due to the ICoS abstract formulation, the rules are applicable to different concrete contexts, and for this reason, there is a need to adapt the rules and put them into perspective according to the local context where they are applied. For the purposes of this research, further and detailed insights into the adaptation of the rules to the study case are provided in chapter 0. An overview of each of the three goals is presented below.

5.1.2 ICoS goal 1: Securing human existence

Ensuring human existence through the central concept of justice promotes the responsible use of natural resources to meet the needs of the present generation, while providing future generations with the opportunity to meet their own needs. This field includes, above all, the *protection of human health* by diminishing the anthropogenic impacts on the environment - noise, ultraviolet radiation, persistent organic pollutants, chemicals with hormonal alteration potential, among others (ICoS rule 1.1).

Health is a fundamental right that allows us to achieve a standard of living of dignity and wellbeing. The United Nations (UN) considers a range of factors to be determinants of health, such as adequate and nutritive food, housing, safe drinking water, sanitation, healthy working and environmental conditions (United Nations, 2008). Health is an important factor to perform any occupation or productive activity. A healthy population with better nutrition would also profit better from learning, developing skills and education. Research in medicine, ecology, biology, and technical sciences warn about the negative effects of hazardous chemicals on the human body, the ways these substances enter the ecosystem and the possibilities of reducing their impact on both people and the environment.

To ensure healthy lives and promote wellbeing for everyone, harmful exposures from all types of environments - air, water, soil - throughout someone's life must be controlled to improve future health outcomes but, more importantly, also to prevent individual, community, and generational detrimental impacts from these exposures. The World Health Organization (WHO) has highlighted prevention in such exposures in children and for women during pregnancy (World Health Organization, 2006). Additional vulnerability in populations related to socioeconomic status, occupation, and other characteristics can greatly influence responses to harmful environmental exposures. Preventive action from the government at all levels is required against adverse health effects from such exposures.

Under the ICoS framework all members of society must be guaranteed a minimum level of basic provision, *Ensuring satisfaction of basic needs* (ICoS rule 1.2): housing, food, clothing, basic medical care, basic services -water, sanitation - as well as protection against key life risks (illness, disability).

Meeting basic human needs is a primary objective of world development which has been embedded in many countries' development plans (Streeten et al., 1981). A suitable operation to provide basic needs should also consider the interconnections among services; for instance, the effectiveness of health services is related to the quality of water access and sanitation facilities. People with a weak immune system or who are malnourished will require more health resources - curative instead of preventive - which will become more expensive and basic health services will become ineffective. Education is also a basic need whose effectiveness is transferred to other areas, such as improved hygiene, better eating practices, suitable water and waste disposal. Furthermore, quality education enriches people's knowledge and skills that could secure them a stable job - if conditions for employment are given - and for the enhancement of their living standards (Dane and Perticará, 2013).

Sustainable development calls for strengthening the individual's capacities to secure their livelihood through pursuing activity undertaken of their own free will to create a prosperous life in which they can realize their rights, live with dignity and make decisions concerning raising a family and securing the elderly (ICoS rule 1.3).

The Declaration of Philadelphia (International Labour Organization, 1944) affirms that full and productive employment and decent work play a key role in reducing poverty. Employment (or self-employment) is not only the means to acquire resources to sustain a living, but it also enhances wellbeing, promotes social abilities - feeling part of a community - enables people to be valued, have self-satisfaction, develop and transfer learned skills, build a solid economic foundation for their own future and their families - children and the elderly - and be healthier (Van Aerden et al., 2017). Citizens in regions where jobs or employment opportunities are scarce, low-waged, or precarious experience greater economic insecurity, the consequence of which could emerge in weak health outcomes, poor housing quality, and low food quality. Moreover, they might also have reduced ability to access education, hence their future employment opportunities decrease, creating a vicious circle.

To secure human existence, the premise of fundamental equality to access natural resources and provide the opportunities to take part in the benefits should be granted (ICoS rule 1.4). Barry states four principles of equality for exerting the use of the resources and fair distribution of opportunities: equal rights, the responsibility of voluntary choices, vital interests and mutual advantage of those involved and affected (Barry, 1997).

Ensuring satisfaction of basic needs, an autonomous subsistence based on one's own income is also related to managing and balancing extreme differences in the distribution of income, social inclusion and wealth (ICoS rule 1.5). If the justice postulates are considered, inequality could be reduced, hence, extreme poverty could be effectively diminished.

5.1.3 ICoS goal 2: Maintaining society´s productive potential

The notion of sustainability encompasses the capability to provide future generations with the opportunity to live a comparable good life, which does not have to be the same as that of the present generation, and meet material needs; it can be demanded as a general goal of sustainable development that the productive capacity of the society must be preserved over time in a very general sense. Our understanding of a good life is to satisfy vital interests such as adequate nutrition, clean drinking water, clothing, housing, health care, education, among others. Equal opportunity across generations should be granted.

The first rule (ICoS rule 2.1) *sustainable use of renewable resources* under this second ICoS goal of *Maintaining productive potential* states that the rate of use of renewable resources shall not exceed their rate of regeneration, and shall not jeopardize the performance and functioning of the ecosystem concerned. Two factors: intensity of use, and how renewable resources are used, are considered.

Soil, water, landscapes, forests, wildlife and biodiversity are resources that have the capacity to renew themselves. In addition, the ecosystem holds the ability to assimilate and degrade waste (see ICoS rule 2.2 below) but these resources can be overused to the point where they are irreversibly damaged. Two key aspects of sustainability are the concern for the future and the recognition of environmental value; these principles imply a change in dealing with economic development within a new conception of resource value. Science has provided warnings of risks of destabilization in the Earth's system if human activities cross the ecosystem's regeneration threshold; consequences could trigger abrupt or irreversible environmental changes that could be catastrophic for human wellbeing. The effects are not limited to regional impacts, as they can permeate or influence the global context. Deep human influence on the ecological system is obligated to preserve this heritage - species, subspecies, varieties, ecosystems - for the generations to come, and must not through human actions cause the extinction of any further form of life on Earth.

The sustainable use of non-renewable resources (ICoS rule 2.2) considers that the extent of the identified non-renewable resources shall be managed and conserved across generations. This principle assumes an efficient (more productive), consistent (replaced by renewable) and sufficient (desist from using) consumption of these finite resources. The ICoS rule 2.2 points out the need for economical use of non-renewable resources and at the same time opens up a gradual way of adapting the economic model to resources that will become scarcer in the future (Kopfmüller et al., 2001).

Humankind has used the natural ability of the Earth's ecosystems to assimilate and potentially degrade waste. To ensure that the Earth continues to provide healthy ecosystems, including food provision, life protection, and recreational purposes, it is vital to manage planetary boundaries adequately. A suitable estimation should provide a safe operating space for humanity concerning the functioning of the Earth's system. Research has aimed to identify the Earth's system processes and attempted to quantify, for each system, the boundary levels that should not be transgressed if humankind is to avoid catastrophic global consequences (Rockström et al., 2009). In addition to these limits, the precautionary principle should be considered so that the most sensitive areas within the system can be reliably protected.

One way to monitor the release of pollutants into the environment is to set targets to reduce human-produced emissions (such as CO_2, SO_2, NOx, NH_3, VOC) which threaten health and the environment, so that the release of these substances shall not exceed the absorption and recovering capacity of the ecosystem (ICoS rule 2.3), and support the stabilization function of nature. Risk guidance should include a degree of degradability over space and time, quantity and impact degree, accumulation effect, and ecotoxicity.

Economic development depends on enabling economic, human and knowledge capital at all levels, starting from a local perspective into regional – state -, national and global levels. In modern society, knowledge capital has become a key factor of competitiveness (Wiek et al., 2011). Human capital is the necessary condition to create and develop knowledge, for which financial capital is needed. A virtuous circle. The relevance of these types of capital does not reside only in its role for knowledge creation and social development, but also in its crucial effect on the promotion of sustainable policies at all levels: economic, social, environmental, that can affect society. In addition, knowledge also has the function of enabling social participation and thus for the realization of social justice.

It is necessary to consider the possibility of incidents and accidents as well as unintended side effects concerning the handling of the risk potential of technologies (ICoS rule 2.4). If they were to occur, it would endanger society's productive potential, and a backlash on appropriate human development could take place. Hence, technical risks with potentially catastrophic effects for humans and the environment are to be avoided. The rule formulated here dictates that, concerning technologies that involve risks with a low probability of occurrence and a high potential for damage, more cautious, less far-reaching, fault-tolerant and, if possible, retrievable alternatives should be sought. In addition to looking for alternatives that are similar in use but pose less risk, solutions that aim either to strengthen safety precautions or to reduce the hazard potential can also be considered.

An important contribution to be inherited by future generations lies in the abilities and faculties to assure economic demand for steady growth to fulfill their own needs and to participate globally. Hence, physical (e.g., tangible assets, equipment, utility networks, roads), human (skills, education) and knowledge capital (e.g., publications, laws, organizational structures, traditions) shall be developed in such a way that economic performance can be maintained or improved (ICoS rule 2.5).

5.1.4 ICoS goal 3: Preserving society´s options for development and action

The principle of not jeopardizing the satisfaction of the needs of future generations is not limited to material needs but also includes intangible ones. Aspects enriching the immaterial facets of the human being – i.e., spiritual and psychological - such as integration in social and cultural relations, communication, education, meditation, aesthetic experiences, leisure and recreation are as important as material ones for wholesome human development. An acceptable level of human existence can be reached when both material and immaterial needs are satisfied.

Hence, the minimum condition to attain this third ICoS goal of Preserving society´s options for development and action would be to grant equal opportunities to access education, information, professional activities, occupation, political positions and socially relevant decision-making processes to every member of society (ICoS rule 3.1). Additionally, education is a necessary precondition of economic development (Lutz, 2015). Education expands the personal planning horizon and leads to responsible decisions. It empowers people to access more information, contextualize it and make conclusions that contribute to personal and societal wellbeing and the development of a country. Attention should be paid to the disadvantaged or vulnerable populations who traditionally are neglected regarding the right of inclusion in governmental policies and programs, which may be based on gender, ethnicity, religion, health condition, disability, etc.

The second step after the recognition of a right to inclusion is the opportunity to take part in all relevant decision-making processes faced by a society in terms of access to education, occupation, information, social, political, and economic positions (ICoS rule 3.2). Every member of society should be granted the opportunity to be an active co-creator of the future development of the community, where their interests and opinions are a helpful way to avoid conflicts between social groups so that human rights could be transformed into civil rights (Kopfmüller et al., 2001).

Citizen participation is important for local government and for the community's further development. Through citizen participation, the needs, wishes and views of the community are made clear and lead to decision-making on behalf of the wellbeing of the region. Through people's participation, confidence in the decision-making process increases, since it emphasizes the inclusion of the community into local governance - and possibly beyond. Limited participation could indicate a lack of hope or aspirations to solve their concerns. A sustainable community in this respect would be a local structure that designs strategies to promote the inclusion of their citizens in a bottom-up approach, i.e., through consultations, workshops, local assemblies, feedback mechanisms, to bring active open and public participation, and engage both the people and governance in a motivated decision-making process.

The importance of preserving cultural heritage and diversity lies in the social bond that culture plays within society. One important aspect of culture is how people live and work together and how people relate to their physical environment, nature, the Earth, and the cosmos. A country's culture reflects its history, customs, institutions, social movements, conflicts, and struggles, both internally and externally, hence, it calls for preservation (ICoS rule 3.3).

The United Nations Educational, Scientific and Cultural Organization (UNESCO) recognizes that development means more than just economic growth; it is "a means to achieve a more satisfactory intellectual, emotional, moral and spiritual existence . . . development is inseparable from culture". Culture contributes to poverty alleviation in terms of social cohesion, hence, the aim is to incorporate culture into all development policies related to education, science, communication, health and the environment (UNESCO, 2017). As is the case with tangible culture, the preservation and maintenance of intangible culture can be threatened by social factors, moreover, it necessarily depends on the actions of humankind for its existence at any time. Therefore, it depends directly on the life circumstances of its bearers. Hence, cultural heritage can be threatened by poverty and vulnerability.

A transparent, participatory and democratic decision-making procedure should be conformed to preserve cultural and natural landscapes, or parts of landscapes with a particular characteristic uniqueness and beauty (ICoS rule 3.4). The opportunity to grant future generations the potential to satisfy their needs cannot be limited to the direct use of resources and as a sink for pollutants, but should also include aesthetic experiences for contemplative, spiritual, religious or recreational experiences (e.g., outdoor sports, animal observation). In addition, we have inherited current landscapes from many previous generations, and we should also provide future generations with the possibility to enjoy the nature we currently have.

Studies have recognized the roles of the natural environment and the lifestyles and livelihoods this enables (Krebs, 2014; Shrivastava et al., 2017). Nature provides for our basic needs (air, water, food), hedonistic needs (sunlight´s stimulating effect, nature´s green is soothing), recreational needs (swimming, hiking) and aesthetic needs, because the experience of landscape beauty is an essential part of human mental wellbeing. Beautiful landscapes have a good physiological and psychological impact on us because they indicate, by the way they look, sound and smell, that they can support human life and provide for its needs, and in addition, to become part of the good human life that makes us feel at home in the world. This aesthetic experience is necessary because it is the connection and recognition of humankind as part of nature (Krebs, 2014). Aesthetics enables moral imagination about complex ethical issues that facilitate a more diversified understanding of multiple perspectives. The existence of nature's landscapes should be preserved so that future generations can have the opportunity to enjoy and make use of the multiple perspectives that nature can provide.

To ensure the social cohesion of society, a sense of law and justice, tolerance, solidarity and an orientation toward the common good, as well as potential for non-violent conflict resolution, must be strengthened (ICoS rule 3.5). Fair social reconciliation of interests and justice are seen as universal, substantial and fundamentally necessary for appropriate social integration of society. These attributes maintain and promote the integration of a society.

5.1.5 Instrumental rules

ICoS differs from other approaches to assessment in making a distinction between the minimum requirements sustainable development must meet, as expressed in the substantial rules – the "what rules" (section 8.1), and the required institutional, political and economic framework conditions which need to be in place in order to implement sustainable development - the "how rules". The framework conditions structured under the instrumental principles are shown in Table 6 (Kopfmüller et al., 2001) as cited and translated in (Grunwald, 2012).

Table 6. ICoS instrumental rules

1. Internalization of ecological and social costs	6. Society's ability to respond
2. Adequate discounting	7. Society's ability of reflexivity
3. Limitation of public debt	8. Society´s ability to govern (steering ability)
4. Fair international economic framework conditions	9. Society's ability of self-organization
5. Promotion of international co-operation	10. Balance of power between societal actors

The instrumental sustainability rules describe ways in which – "how" - the substantive rules – "what" - can be implemented. One factor that accounts for a sustainability deficit is the oversight of significant ecological and social aspects in the economic process for the production and consumption of goods and services (rule 1). These external costs include reductions of ecological reserves as well as losses of quality of life, hazardous working conditions in a physical or psychological aspect, e.g., stress, erosion of social relationships, unemployment, child labor. These costs entail valuation challenges which need to be incorporated to a limited extent.

Discounting, at the societal level, in the sense of a "time preference of society", is justified mainly in terms of promoting intergenerational equity (rule 2). It is argued that current generations would only be able to access a share of the larger social product potentially available to future generations and therefore, correct distributional inequalities between generations, with the help of discounting.

The goal of an appropriate fiscal policy must be to realize an optimal level of debt in terms of its scope and structure, which allows sufficient funds to be made available for important future investments but does not lead to unacceptable burdens on current or future generations (rule 3).

To provide a degree of fairness to global economic processes in the form of an equal distribution of opportunities and participation, including the poorest low-income economies (rule 4), increased transparency among actors, improved banking supervision, improvements of existing regulations, e.g., customs duties, are proposed.

A call for international cooperation among the different actors whose focus is directed at the main areas of decisive importance for achieving global sustainable development (rule 5): safeguarding global public goods, i.e., health, public security, harmonious environmental conditions, fairness, justice, knowledge and research; strengthening good governance, legal system; the role of environmental and social standards in global trade, the creation of suitable institutions or institutional arrangements, the promotion of appropriate innovation processes and the educational systems necessary for them.

The ability of a society to perceive and react to changes in its environment is given by its resonance capacity, as in increasing environmental awareness, for example; adequate coordination of the different subsystems is required so a society can be proved functional (rule 6). Institutional structures need to be created to make social and ecological issues the subject of their observations to a greater extent, in order to process information and react in a timely manner. Reflexivity (rule 7) implies the anticipation of the consequences before the execution of the actions. To this end, suitable information capacities must be built and networked, and mutual coordination processes must be institutionalized.

A sustainable society should be capable of realizing the necessary changes in people's lifestyles, modes of production and patterns of consumption through a certain degree of steering capability (rule 8) as a relationship between systems and the environment, and not as the traditional instrument of control coming from a superior to the subordinate.

The emergence of order structures within civil society, organized in networked structures of mutual consultation within politics, business, science and other areas of society must be promoted (rule 9). These participatory forms of decision-making structures for achieving the goals of a sustainable society are relevant because they are able to build their strategies rather than being imposed from a superior configuration, since they increase the quality of problem solutions, and promote an inclusive society.

A different distribution of power can lead to a barrier to sustainable development, therefore, it is necessary to include strategies for balancing and solving conflicts to ensure that the divergent actors are able to participate in decision-making processes (rule 10). In this way, it should be guaranteed that multiple sustainability impulses can be effectively introduced into the political discourse.

5.2 Cross-Impact Balance

The overall idea of the Cross-Impact Balance (CIB) analysis is to generate possible scenarios, in this case, of the solar energy system in rural Mixteca, which address not only techno-economic variables, but also societal non-quantitative variables, like culture, politics, or the environment.

The selected CIB approach offers useful advantages for the purposes of this analysis. Its qualitative orientation with respect to judgments and evaluation procedures meets the typology of data faced in this research; it balances logic with a theoretical basis of the system; and has proven successful in diverse and multiple research fields such as waste (Meylan et al., 2013), water (Schütze et al., 2019), politics (Mowlaei et al., 2016), education (Yaghoobi et al., 2018), health (Hummel and Hoffmann, 2016), mobility and transport (Kurniawan, 2018), and energy (Norouzi et al., 2020). A thorough list of bibliography is available in (Weimer-Jehle).

The CIB approach is implemented in steps (Weimer-Jehle, 2018; Weimer-Jehle et al., 2016). First, the most important factors that determine the solar energy system and their possible future forms are identified and brought into effect. Their interdependencies are then analyzed using participatory approaches and expert judgments. With the help of the CIB balance algorithm (see www.cross-impact.de), configurations are sought, in which the values assigned to the factors promote or inhibit each other. From the combinatorial diversity of possible developments, only those configurations which form a “consistent" network of mutually plausible assumptions are identified; these are subject to interpretation and story formulation. It must be noted that the selection of factors and the interdependencies are based on expert assessments, and the analysis therefore only covers the implications of the system view of the participating experts. Yet, this applies in an analogous way to model-based scenarios. The workflow for constructing CIB-based context scenarios for this research can be outlined using the following steps:

1. **Defining the context.** A selection of descriptors which characterizes the solar energy system of Mixteca needed to be defined and understood as a socio-technical system. Given the case that the final intention was to perform a sustainability assessment, the main goals of sustainability and its rules were taken into consideration during the selection process, trying to obtain a group of criteria that could be addressed through the ICoS rules

detailed in section 5.1. The selected descriptors represent social and cultural aspects, i.e., emigration, ethnic identification, education, community organization and women's empowerment, and political features, such as governance uncertainties, governmental policies for integrated energy system and legal system. Economic facets consisting of job and earnings, wealth distribution and financial markets are also addressed. Environmental factors such as climate change and its impacts on the population are included under the model input data. As described in section 2.3, the collection of information as well as the identification of the future uncertainties and interdependencies among the data is undertaken through participatory approaches and expert judgments (Weimer-Jehle, 2006), since awareness of the local meaning associated with its impacts is important (Vanclay, 2002). For this research, literature search and participative methods were used. A series of interviews between different types of experts and a field trip to the region produced a set of eighteen descriptors. The experts have solid experience in rural development, sociology, energy research, technology assessment and policy, and the panel was formed by members of recognized affiliations such as CONACYT (Consejo Nacional de Ciencia y Tecnología -Mexican Council of Science and Technology); Mexican scientific thematic networks; non-governmental organizations (NGOs) with a local presence in Mixteca; consultants; a cooperative representative, a private company with social responsibility in the area and members of governmental institutions within a workshop of community representatives. In addition, five communities in Mixteca were visited, where nineteen families were interviewed during a field trip in July-August 2019. The complete list of descriptors is presented in detail in chapter 0, with the list of stakeholders and their affiliations (Table 7, chapter 6).

2. **Identifying the future uncertainties.** A set of two to four alternative future states are defined and assigned to each descriptor to address uncertainties. These future uncertainties were selected through the group of experts involved. It is important to note that the identification of future uncertainties, as well as the impact judgments between descriptors (step 3), needed to be approached within the identified stakeholders - including the community members. This is because a proposed transition to a solar energy system would play a significant part in their daily lives, their interaction with one another; within their culture (values, customs and shared beliefs); in their community, their cohesion, services, facilities; their governance, the extent to which people are able to participate in decisions that affect their lives and their community resources; their environment, their access to and control of natural resources, the quality of air and water and disposition of waste, adequacy of sanitation; their personal and community wellbeing; their future perspective as a community and for their children's future.

   Given the diversity of stakeholders, the set of descriptors was evaluated according to each one's expertise. This means that not all sets of descriptors and interrelationships were evaluated by every one of the experts. The descriptors were divided into four sets: *solar and renewable energy, social and rural development*, *governance, and economy*. In some cases, only a few stakeholders ventured to evaluate descriptors which fell at the threshold with descriptors which were not completely related to their field of expertise. In other cases, the experience of other energy transitions in circumstances comparable to those of Mixteca would provide insights. For each selected descriptor a range of 2 to 4 future states were identified. An important remark in the selection of future states is that this process was performed without considering the ICoS sustainability rules, and trying to capture a plausible future regardless of a degree (or lack) of sustainability. The reason was to identify scenarios which could reflect a future for Mixteca as close as probable given the current conditions in the area. Figure 21 depicts an example of the identified states, in this case, three states for each descriptor. From this figure we see that even though state C1 (where education level for the area could be less than 5 years in the future), and state P2 (where legal systems seems to worsen in the future compared to status quo), both states are not an optimistic situation and would not depict a sustainable future. However, both states could be possible so they should not be discarded, but considered as possible alternatives in the future for Mixteca. The complete set of selected descriptors and their alternative futures for the region under review are summarized in Table 8, in chapter 0.

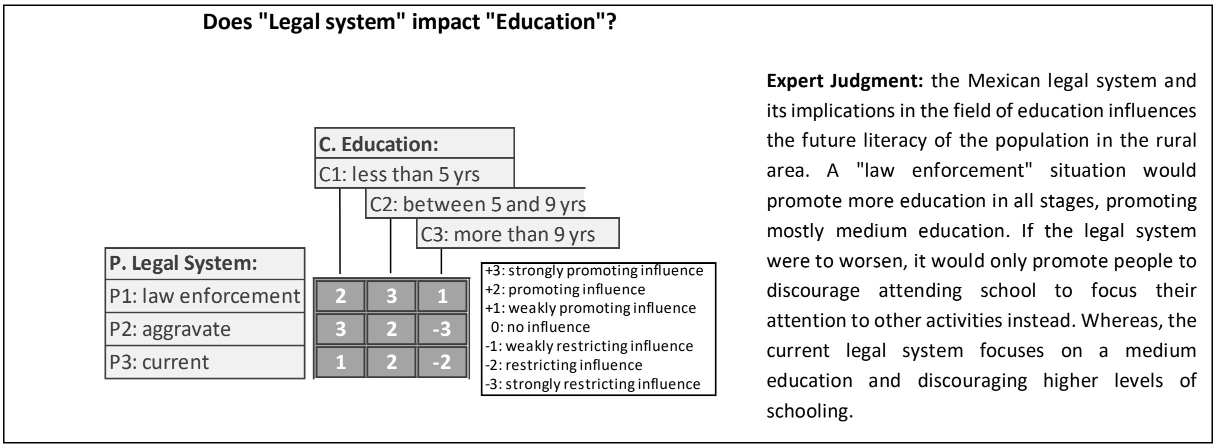


Figure 21. States identification and impact judgments: example to show how "legal system" influences descriptor "education"

3. **Identifying the interdependencies and building up the Cross-Impact Matrix (CIM).** The interrelationship between descriptors were valued using an integer, ranging in our case from -3 to +3, where -3 indicates a strong trade-off relation, -2 a restricting influence, -1 a weakly restricting influence, 0 no influence, whereas +3 indicates a strong supporting relationship, +2 a promoting influence, +1 a weakly promoting influence, see Figure 21. The states in the rows of the cell indicate the source of influence, while the columns show the receiving influence (targets). One important consideration to bear in mind, as pointed out by (François, 2022), is that although the CIB approach assigns value zero to non-influential factors, in his research François calls for caution; he evidences a plurality of judgments that might occur in opposing opinions leading to a net zero value that does not necessarily involve a lack of influence, despite the existence of positive and negative influences between the analysis of trends. Further analysis needs to back up the zero-value judgment before assuming a lack of influence. In Mixteca's case, the qualification of the interdependencies was done with the assistance of the stakeholders. However, the exception was that the judgments were not evaluated by the community members since an expert overview of the plausible future of the region was needed. Considering that more than one expert provided a judgment for a set of interrelationships, the median value was used to determine the overall level of influence between one descriptor and another. It was decided to use the median and not an average to avoid extreme low or

high values, thus the median is more reliable at capturing a common evaluation than the average value. An example of the judgment evaluation is shown in Figure 22.

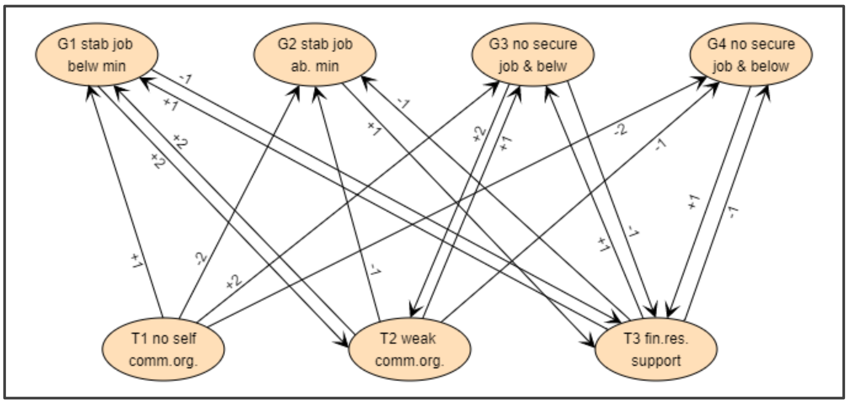


Figure 22. Exemplary network interrelationship between two descriptors and its states.

Figure 22 shows the influence (promotes: + or hinders: -) and its degree (here: -2…+2). Descriptor G can exert influence on descriptor T (active) and at the same time descriptor G can be influenced by descriptor T (passive).

The compilation of all the descriptors-states judgment evaluations is shown in the Cross-Impact Matrix (CIM) in Figure 23. This matrix is the input for step 4 of the construction of scenarios through the CIB algorithm.

	A.Emigr			B.Eth.id			C.Educ			D.Src inc.			E.Bas.serv				F.REpop			G.Job&earn				.Gov.uncer			I.PolES		.EnR&D		M.3coop			. AVRe		O.Fin.mkt			P.Leg.sys			Q.Clchg		Env-po		S.Wemp			T.CoOrg		
	A1retmig	A2permw/b	A3permw/o	B1low	B2high	B3pluri	C1<5 yrs	C2-5-9	C3>9yrs	D1labour	D2remitt	D3lab+rem	E1none	E2prt-wtr	E3prt-elect	E4all	F1noself	F2wk	F3fin.res	G1stbel.min	G2stabv.min	G3nosec-bel	G4nosec+ab	H1low	H2strw/grw	H3strw/out	I1(-)	I2(+)	J1low	J2high	M1low	M2+	M3++	N1no	N2yes	O1ltd.form	O2acc.inf.	O3none	P1law enf.	P2aggrav	P3current	Q1high	Q2low	R1high	R2low	S1no	S2full	S3part	T1noself	T2wk	T3fin.res
A. Emigration																																																			
A1 return emigration				-1	2	2	-1	1	-1	1	-1	-1	0	0	0	0	0	1	1	1	1	1	1	-1	1	1	0	0	0	0	-1	1	1	1	-1	1	2	0	0	0	0	0	0	0	1	-1	1	1	0	0	0
A2 perm w/bond				-1	2	1	2	2	-2	0	2	2	-2	1	1	1	0	-1	2	1	-1	1	-1	-1	1	1	0	0	0	0	1	-1	-1	1	-1	0	1	0	0	0	0	0	0	-1	1	-2	2	1	0	0	0
A3 perm without bond				2	-1	2	-1	1	-2	0	-1	-1	0	0	0	0	0	-1	-1	1	-1	1	-1	-1	1	1	0	0	0	0	1	-1	-1	1	-1	0	0	0	0	0	0	0	0	-1	1	-2	2	2	0	0	0
B. Ethnic identification																																																			
B1 low	1	1	2				-1	1	1	1	1	1	-1	2	2	1	0	0	0	-1	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	1	0	-1	2	-2	0
B2 high	1	-1	-2				1	1	-1	2	-1	-1	1	1	1	-1	0	0	0	2	-2	1	-2	0	0	0	0	0	0	0	0	0	0	0	0	-2	-1	2	0	0	0	0	0	0	0	-2	0	2	-2	2	0
B3 pluricultural	2	1	2				-1	2	1	1	2	2	-1	1	1	2	0	0	0	-1	2	-1	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	-1	0	0	0	0	0	0	0	-1	0	1	-1	1	0
C. Education																																																			
C1 <5 yrs	1	2	2	0	0	0				1	2	1	2	1	1	-1	0	1	-1	2	-2	2	-1	0	0	0	1	-1	1	-1	0	0	0	2	-2	-3	0	2	-2	2	0	2	0	2	-2	1	-1	-1	0	0	0
C2 5-9 yrs	2	1	1	0	0	1				1	1	1	-1	2	2	0	0	1	1	1	0	1	0	0	0	0	1	-1	0	0	-1	1	2	-2	2	0	2	-2	1	0	1	0	0	-1	1	-1	-1	1	0	0	0
C3 >9 yrs	-1	2	2	2	-1	2				2	0	0	0	2	2	2	0	2	2	-1	2	-1	1	0	0	0	-1	1	-2	2	0	0	0	-3	3	2	2	-2	2	-2	0	0	0	-2	2	-1	2	1	-1	0	1
D. Source of income																																																			
D1 labor	2	-1	1	-1	2	0	1	1	-3				-1	1	2	1	0	1	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-2	0	0	0	0	0	0	0	-2	2	1	0	0	0
D2 remittances	1	2	2	0	0	1	1	1	-2				-1	1	2	1	0	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	-2	0	0	0	0	0	0	0	-1	-1	1	0	0	0
D3 rem + labor	1	-1	1	0	0	1	1	1	-1				-1	1	2	2	0	2	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	-2	0	0	0	0	0	0	0	-1	1	1	0	0	0
E. Basic services access (water, electricity, drainage)																																																			
E1 none	1	2	2	0	0	0	2	-1	-2	-2	0	0					0	1	-2	1	-1	2	-1	0	0	0	-2	2	-1	1	-1	1	1	-2	2	-3	-2	3	0	0	0	0	0	-1	1	-1	0	1	-2	2	0
E2 part-water	1	1	1	0	0	0	1	-1	-1	1	0	0					0	1	1	1	-1	1	-1	0	0	0	-2	2	-1	1	-1	1	1	-2	2	-1	1	-1	0	0	0	0	0	2	-2	0	0	0	-2	2	0
E3 part-electricity	1	1	1	0	0	0	1	1	-1	2	0	0					0	1	1	1	-1	1	-1	0	0	0	-2	2	-1	1	-1	1	1	-2	2	-1	1	-1	0	0	0	0	0	0	0	0	0	0	-2	2	0
E4 all	-1	-1	-1	0	0	0	-2	2	1	2	0	0					0	0	2	-1	2	-1	2	0	0	0	1	-1	1	-1	1	-1	-1	1	-1	1	2	-2	0	0	0	1	0	1	-1	0	0	0	0	1	1
F. Population acceptance of renewable energy plans and participation																																																			
F1 poor organization	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	-2				0	0	0	0	0	0	0	0	0	0	0	2	-1	-2	2	-2	-1	-1	1	0	0	0	1	-1	3	-3	0	0	0	1	-1	-1
F2 limited to labor	-1	-1	-1	0	0	0	-1	1	2	1	-1	-1	-1	1	1	1				1	1	-1	1	0	0	0	-1	1	-1	1	-1	1	1	-2	2	0	1	-1	0	0	0	-1	1	-1	1	0	0	0	-1	1	0
F3 financial resources	1	1	0	0	0	0	-1	2	1	1	1	1	-2	2	2	2				1	1	-1	1	0	0	0	-2	2	-2	2	-2	2	2	-2	2	1	1	-1	0	0	0	-1	1	-2	2	0	0	0	-1	0	1
G. Job and earnings																																																			
G1 stab job belw min	1	2	2	0	0	0	1	2	-1	2	2	2	1	1	1	-1	0	2	-2					0	0	0	0	0	-1	1	-1	1	1	0	0	-2	1	-1	0	0	0	0	0	0	0	2	-2	-2	0	2	-1
G2 stab job ab.min	-2	-2	-2	0	0	0	-1	2	2	2	-1	0	-1	1	1	1	0	1	1					0	0	0	0	0	0	0	1	-1	-1	0	0	2	1	-1	0	0	0	0	0	0	0	-2	2	1	0	0	1
G3 no secure job&below	3	3	3	0	0	0	2	-2	-3	0	2	2	2	-1	-1	-2	0	1	-2					0	0	0	0	0	-1	1	-1	1	1	0	0	-2	-1	2	0	0	0	0	0	0	0	2	-2	-2	0	2	-1
G4 no secure job above	-1	2	2	0	0	0	1	2	-1	2	-2	0	-1	1	1	1	0	1	1					0	0	0	0	0	0	0	1	-1	-1	0	0	-1	1	-1	0	0	0	0	0	0	0	-1	2	1	0	0	1
H. Governance uncertainties																																																			
H1 low	-1	-1	-1	0	0	0	-2	2	1	2	1	1	-1	1	1	1	-1	1	1	2	2	-1	1				-2	2	-1	1	-2	1	2	-2	2	1	1	-2	2	-2	1	0	0	-1	1	0	0	0	0	0	0
H2 strong with growth	-1	1	1	0	0	0	-1	2	2	1	0	0	-1	1	2	1	1	1	-1	1	1	1	2				-1	1	1	-1	1	-1	-1	1	-1	-1	2	-1	1	-1	1	1	-1	1	-1	-2	2	2	-1	1	1
H3 strong without growth	2	1	1	0	0	0	2	-1	-2	-2	2	2	1	-1	-1	-2	2	1	-2	-1	-2	2	-2				2	-2	2	-2	2	-1	-2	2	-2	-2	-1	2	-2	2	1	1	-1	2	-2	-2	2	2	-1	1	-1
I. Governmental policies for integrated energy system																																																			
I1 restrictive	1	2	2	0	0	0	1	2	-2	-1	0	0	2	-1	-1	-1	1	-1	-1	1	-1	1	-1	-2	1	1			3	-3	1	-1	-1	2	-2	-1	1	-1	0	0	0	2	-2	3	-3	0	0	0	0	0	0
I2 supportive	-1	-2	-2	0	0	0	-2	2	2	2	0	0	-2	2	2	2	-1	1	1	-1	1	-1	1	2	1	-1			-3	3	-1	1	1	-2	2	1	1	-2	0	0	0	-2	2	-3	3	0	0	0	0	0	0
J. Investments in energy research																																																			
J1 low	0	0	0	0	0	0	1	1	-2	-1	1	1	2	1	1	-2	1	-1	-2	1	-1	1	-1	-1	0	-1	1	-1			2	-1	-2	2	-2	0	0	0	0	0	0	2	-2	3	-3	0	0	0	0	0	0
J2 high	0	0	0	0	0	0	-2	1	2	1	-2	0	-2	1	1	2	-1	1	2	-1	2	-1	1	1	-1	-1	-1	1			-2	1	2	-2	2	0	0	0	0	0	0	-2	2	-3	3	0	0	0	0	0	0
M. Cooperation between government, private investors, NGOs																																																			
M1 no/low	1	1	1	0	0	0	1	1	-1	-1	1	1	2	-1	-1	-2	2	-1	-1	1	-1	2	-1	-1	1	1	2	-2	2	-2				2	-2	-1	2	-1	-2	2	1	1	-1	2	-2	2	-2	-1	0	0	0
M2 good	-1	-1	-1	0	0	0	-1	1	1	1	-1	-1	-1	1	1	1	-1	1	1	-1	1	-1	1	1	1	-1	-2	2	-2	2				-1	1	1	1	-1	1	-1	-1	-1	1	-1	1	-1	1	1	-1	1	0
M3 excellent	-2	-2	-2	0	0	0	-2	2	2	2	-2	-1	-2	1	1	2	-2	1	2	-1	2	-2	1	2	1	-2	-3	3	-3	3				-2	2	2	-1	-2	2	-2	-1	-2	2	-2	2	-1	2	1	-1	0	1
N. Added Value creation from the renewable energy sector																																																			
N1 no/low	0	0	0	0	0	0	0	0	0	-1	0	0	1	-2	-2	-2	2	-2	-2	1	-1	1	-1	-1	0	0	2	-3	3	-3	2	-1	-2			0	0	0	0	0	0	1	-1	2	-2	0	0	0	0	0	0
N2 yes/good	-1	-1	-1	0	0	0	-2	2	2	2	0	0	-2	2	2	2	-2	2	2	-1	2	-1	1	1	0	0	-3	3	-3	3	-2	1	2			0	0	0	1	0	0	-1	1	-2	2	0	0	0	-1	1	1
O. Financial market in rural economy																																																			
O1 limited access to form	-1	-1	-1	0	0	0	0	1	-1	1	2	2	-1	1	1	1	1	1	1	1	1	-1	1	1	0	-1	-2	2	0	0	2	1	2	0	0				0	0	0	0	0	-1	1	-2	2	2	-1	0	1
O2 access to informal	0	0	0	0	0	0	1	1	-1	2	1	2	-1	1	1	-1	1	1	1	1	-1	1	-1	0	1	1	0	0	0	0	2	1	-1	0	0				0	0	0	0	0	0	0	-2	2	2	-1	1	1
O3 no access to any	1	2	2	0	0	0	2	1	-2	2	2	2	2	-1	-1	-1	-1	2	-2	1	-2	1	-1	0	0	0	1	-1	0	0	1	-1	-2	0	0				0	0	0	0	0	1	-1	2	-2	-2	-1	1	-2
P. Legal System																																																			
P1 law enforcement	-2	-1	-1	0	0	0	2	3	1	2	-1	-1	-2	2	2	2	-1	1	1	1	2	-2	2	2	-1	-2	-1	1	-1	1	-1	2	3	-2	2	2	1	-2				0	0	-2	2	-2	2	1	0	0	0
P2 aggravated	2	2	2	2	-1	0	3	2	-3	1	2	2	2	1	1	-2	1	1	-1	2	-3	3	-1	-2	-1	2	1	-1	2	-2	3	-2	-3	2	-2	-2	2	2				0	0	1	-1	2	-2	-1	-1	2	-1
P3 as current	1	1	1	0	0	0	1	2	-2	1	1	2	1	1	2	-1	0	1	-1	1	-2	2	-1	-1	1	2	1	-1	1	-1	2	-1	-1	1	-1	-1	1	0				0	0	1	-1	1	-1	-1	-1	1	-1
Q. Climate change																																																			
Q1 high impact	1	2	2	0	0	0	1	1	1	2	0	0	2	2	2	-2	-2	2	1	1	-1	2	-2	0	0	0	-2	2	-2	2	-1	1	1	-2	2	-1	1	-1	-1	1	1			3	-3	0	0	0	-1	1	1
Q2 low impact	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	1	1	0	0	0	-1	1	-2	2	0	0	0	0	0	0	0	2	-1	-1	0	0	0	0	0	0	0	0			-3	3	0	0	0	0	0	0
R. Environmental effects on population																																																			
R1 high impact	1	2	2	0	0	0	1	-1	-1	2	0	1	2	1	1	-2	-2	2	-1	0	0	2	-2	0	-1	1	-2	2	-2	2	-2	1	2	-2	2	-2	-1	2	-1	1	1	0	0			0	0	0	-2	2	-1
R2 low impact	0	0	0	0	0	0	-1	1	1	-2	0	-1	-2	-1	-1	2	1	-1	-1	0	1	0	1	1	0	-1	0	0	0	0	2	-1	-1	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
S. Women's empowerment																																																			
S1 limited or none	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	2	0	0	0	0	0	0	0				0	0	0
S2 fully attained	-1	-1	0	0	0	0	-1	0	1	2	0	0	0	0	0	2	0	0	2	0	0	1	1	0	0	0	0	0	0	0	-1	1	2	0	0	1	2	-2	1	-1	-1	0	0	0	0				0	0	0
S3 partial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-1	1	1	0	0	1	1	-1	0	0	0	0	0	0	0				0	0	0
T. Community organization																																																			
T1 poor organization	1	1	1	2	-2	1	1	-1	0	-1	1	1	2	-1	-1	-2	2	-1	-1	1	-2	2	-2	-1	-1	1	0	0	0	0	2	-1	-1	0	0	0	0	0	0	0	0	2	-2	2	-2	0	0	0			
T2 limited to labor	-1	-1	-1	-1	2	1	-1	2	0	2	-1	-1	-1	1	1	0	-1	2	-1	2	-1	1	-1	1	1	-1	0	0	0	0	-1	1	1	0	0	0	0	0	0	0	0	-1	1	0	0	0	0	0			
T3 financial resources	-2	-2	-2	0	0	0	-1	2	0	1	1	1	-2	2	2	2	-1	0	1	1	-1	1	-1	1	1	-1	0	0	0	0	-1	1	1	-1	1	0	1	-1	1	-1	-1	-1	1	-1	1	0	0	0			

Figure 23. Cross-Impact Matrix (CIM)

4. **Constructing and analyzing the scenarios**. Using ScenarioWizard v4.31 (www.cross-impact.org) consistent combinations of descriptor-states are identified. Each consistent combination of all descriptors describes a scenario. The scenarios are analyzed to identify relevant driving forces and the political, societal, economic, and technological conditions of possible future developments. The nature of the Cross-Impact Balance analysis is to analyze multidisciplinary connections, and the ability of the CIB to take indirect impacts into account is therefore essential to the strength of the method to assist in understanding complex systems behavior. The combination of the states of all descriptors gives us the possible combinational scenarios. For the solar energy system proposed for Mixteca, this number results in 90'699,264 possible configurations[3]. Through the CIB algorithm, all possible combinational scenarios can be automatically scanned and the reduced number of scenarios identified without contradictions, i.e., consistent, can be selected. The Mixteca case records only 8 scenarios that satisfy a self-consistency criterion and are accepted to be context-'consistent scenarios'. A balance between the highest impact totals for the different impact balances and the possible contradictory influence are compared; the stronger influences impact proves the deciding factor. The consistent scenarios particularly stand out from the mass of combinatorially possible scenarios due to their total self-consistency (Weimer-Jehle, 2018). The self-consistency of a scenario requires that every state is chosen in such a way as to ensure that no other state of the same descriptor is preferred more strongly by the combined influences of the other descriptors - principle of consistency. One graphical example of an inconsistent versus consistent scenario in the Mixteca case is shown in Figure 24. The negative influences on state H1 'Low governance uncertainties' promoted by A1 'return emigration' (weight -1), I1 'restrictive policies on new energy systems' (weight -2), J1 'low investments or none on energy research' (weight -1), M1 'nonexistent or low cooperation between government, private investors, NGOs' (weight -1), N1 'nonexistent or very low added value creation from the renewable energy sector' (weight -1); T1 'poor community organization' (weight -1), outweigh the supportive influences from O1 'limited access to formal financial market' (weight 1) and P1 'law enforcement in legal system' (weight 2); i.e., -7 negative impacts vs +3 positive impacts. This assumption shows a net impact score of -4 (top figure). In consequence, the arguments contradicting this assumption are predominant. In contrast, the alternative assumption H3 'strong uncertainties in the governance without growth' shows a net impact score of +1 between the balance of promoting influences A1 'return emigration' (weight +1), M1 'nonexistent or low cooperation between government, private investors, NGOs' (weight +1), N1 'nonexistent or very low added value creation from the renewable energy sector' (weight +1), T1 'poor community organization' (weight +1), I1 'restrictive policies on new energy systems' (weight +1) and restricting impacts driven by J1 'low investment or none on energy research' (weight -1), O1 'limited access to formal financial market' (weight -1) and P1 'law enforcement in legal system' (weight -2) see bottom section in Figure 24. This makes the alternative assumption H3 (bottom) more plausible than scenario assumption H1 (top), therefore, scenario H1 is inconsistent and is discarded.

[3] The product of the number of states of the 18 descriptors in Mixteca's system results on the possible number of combinations of the matrix as follows: 3x3x3x3x4x3x4x3x2x2x3x2x3x3x2x2x3x3 (Weimer-Jehle, 2018)

Further details on the eight consistent scenarios identified for the solar energy transition in Mixteca, along with a compilation of states shown in Figure 28, can be found in chapter 0.

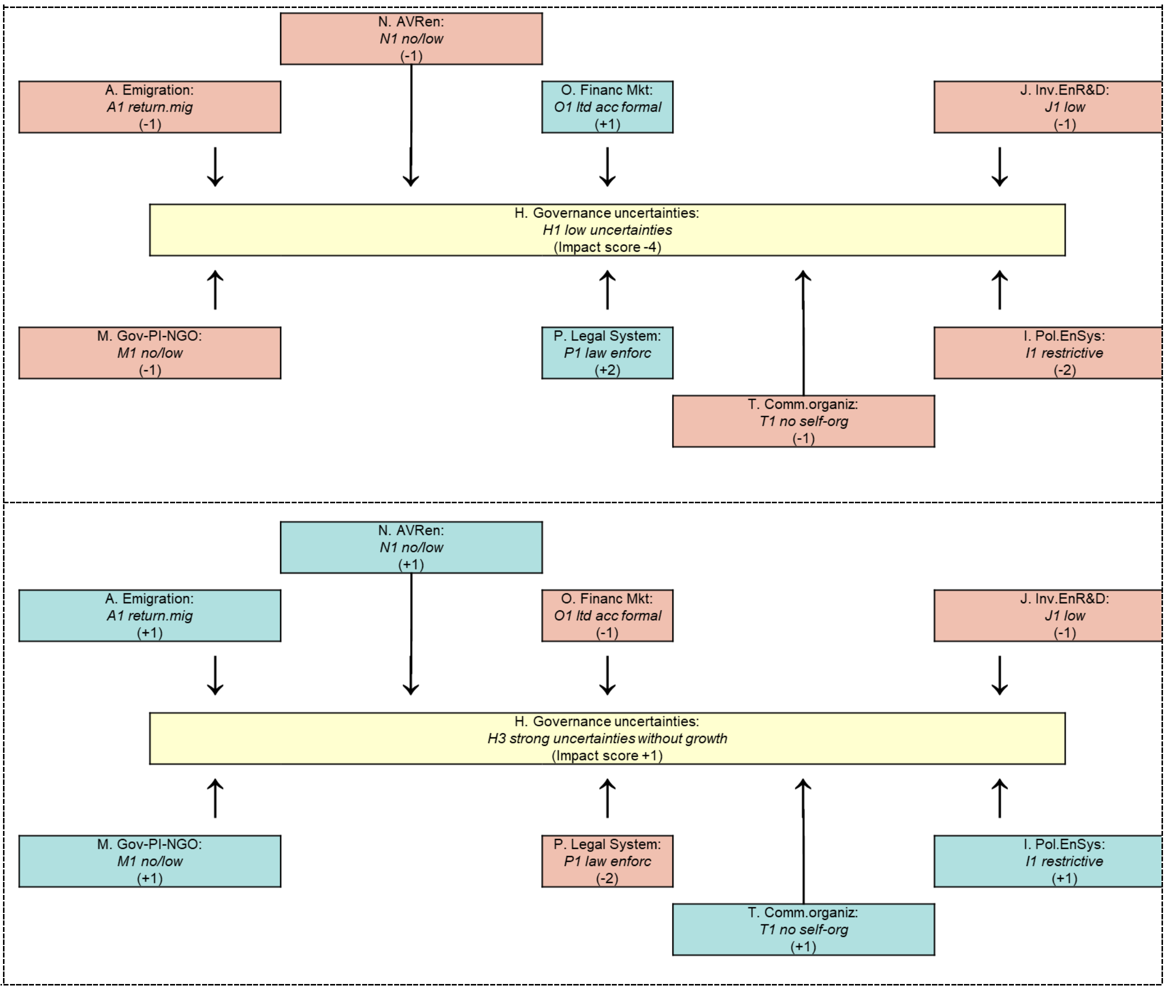


Figure 24. Influences on the scenario descriptors H1 and H3. Influences on "H1 Low governance uncertainties" (top) versus influences on descriptor "H3 Strong uncertainties in Governance without growth" (bottom).

5.3 CIB - ICoS Integration: 'Scenario-based sustainability assessment'

The need for a procedural approach for sustainability assessment is outlined in section 2.2.2. It highlights the importance of setting adequate system boundaries for a proper definition of the system, as well as for monitoring its future performance. A recognized challenge of sustainability assessment is the need to systematically identify (in a scientifically-based way) what contributes (and what does not) to a sustainable future. A consistent or coherent (quality criteria of scenarios, see section 2.3.2) description of a sustainable future is still missing (Sala et al., 2015). Assumptions about the future are not clearly framed into a reliable methodology (Grunwald and Rösch, 2011). The societal aspects interrelated within the boundaries are essential elements, but there is an unclear vision on how to consider them in the future assessments. The holistic nature of the approach is no further along in discussion, nevertheless, the way these environmental, socio-technical, and economic dimensions evolve over time and space (spatial differentiation) is still contested; hence, the diverse societal contexts through which sustainability unfolds are still narrowed to one dimension at a time, thereby missing potential conflicts and trade-offs among the multiple direct and indirect interrelationships (Köhler et al., 2019).

Section 2.3.4 provides support from the scarce research for the methodological need to close the gap between a procedural approach that links the sustainability assessment based on future scenarios in a consistent, comprehensive and systematic way. It is of note that these are also quality criteria for scenarios (see section 2.3.2). Sustainability assessments of scenarios do not currently have a standard or accepted methodology, despite their importance having been acknowledged (Arushanyan et al., 2017; Fauré et al., 2017). A few proposals have emerged (Kopfmüller et al., 2021; Pargman et al., 2017) in an effort to address the scenario evaluation methodology, although these are still lacking practicability, in the first case, and in the second addressed specifically to the ICT scope.

In their research, Kopfmüller et al. (2021), propose an integrative methodology to assess scenarios to support decisions in the energy transition. The main differences between their proposal and this study lie in (1) the distinction of criteria into two types and for each of them a different assessment is needed: the use of an energy system model and an environmental impact assessment are applied for model-based criteria (quantitative data), while for the non-model-based criteria (qualitative data) expert judgements was required. (2) The need to standardize the evaluation results of the two types of criteria to ensure comparability requires normalization of the results. (3) Multiple steps with different procedures (e.g. archetype-based typification of scenario performances) and differentiation of criteria are mostly performed in the framework of complex processes, often requiring stakeholders' judgement and discussions from the beginning to the end of the process. (4) The application for detailed analysis of cause-impact-circumstances is useful while it can be resource intensive for average assessments with cost and time limitations. Despite its overall complexity and lengthy procedure, the method allows for a transparent and procedural application.

In contrast, the *Scenario-based sustainability assessment* proposed in this dissertation, seeks to provide a straightforward alternative for assessing future scenarios by allowing a single type of criteria -assessing quantitative and qualitative data in the same step- integrating two approaches in which descriptors / criteria are selected from the same boundary conditions and contextualized to local problems without the need to normalize the results. The procedure of the *Scenario-based sustainability assessment* is step-based but articulated in a comprehensive and uncomplicated process. Stakeholders are an important part of the approach, especially during the definition of the framework conditions, but the assessment does not dependent entirely on their judgements but on the scenario results. This approach can be applied and transferred in various aspects to different contexts (see chapter 0).

This study reflects and adds to the discussion by providing a structured and systematic method to address sustainability assessment of scenarios with a focus on societal features inclusion. Using the Mixteca case in order to evaluate the sustainability of the future paths of a solar PV energy transition in the poverty-ridden region in a systematic way, it is proposed to integrate the two approaches; bringing together the scenario analysis provided by the CIB, and the sustainability aspect brought by the ICoS rules, in a way that works with the inherent complexity of the social value of energy. A schematic diagram on how the proposed integration would work is shown in Figure 25.

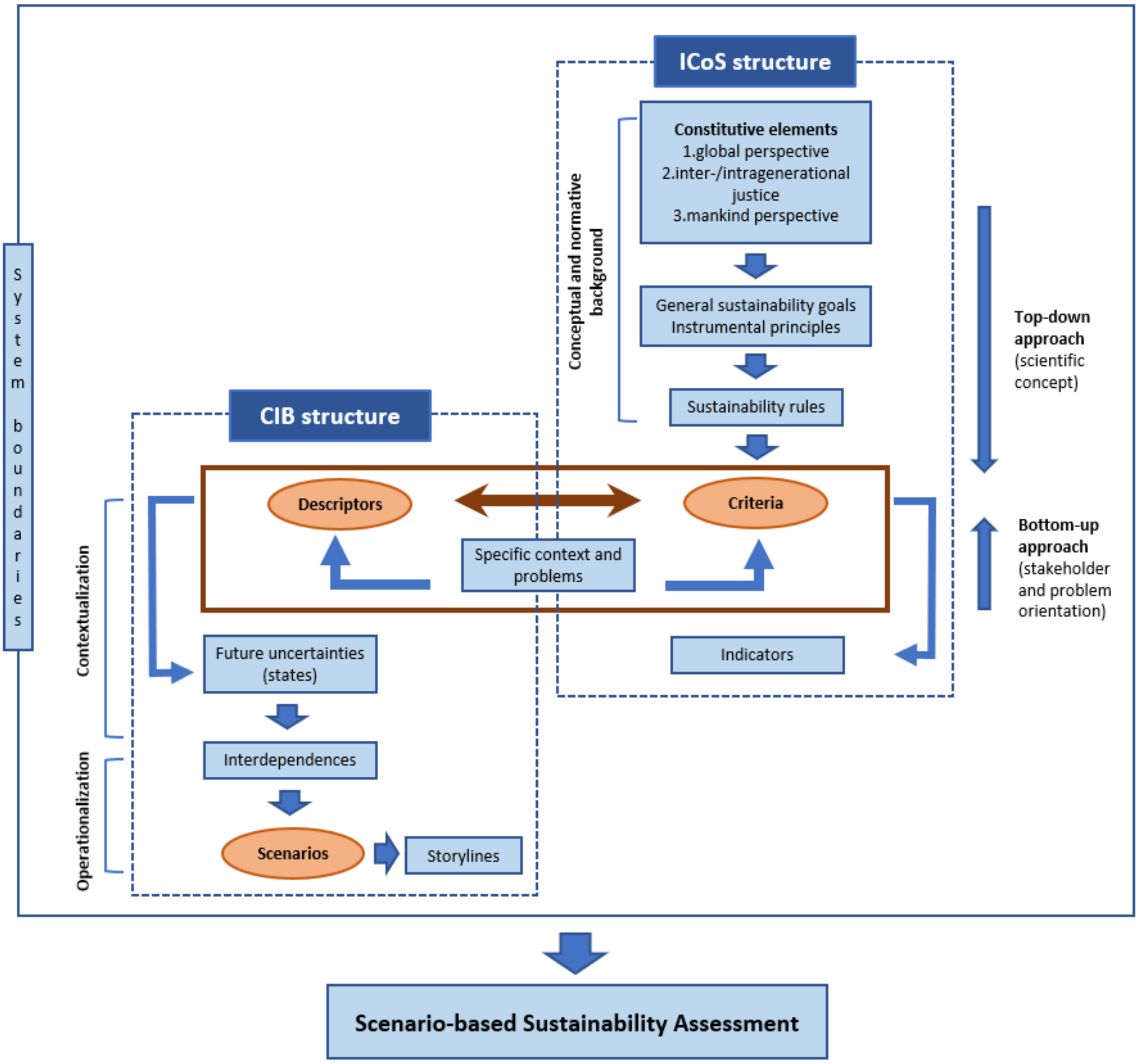


Figure 25. Schematic representation of the 'Scenario-based sustainability assessment'. The figure shows the identification of descriptors and criteria as common contextual stage within both structures. Author's depiction based on (Jörissen et al., 1999); (Kopfmüller et al., 2001); (Grunwald, 2016); (Weimer-Jehle, 2006).

In the following sections, the terms descriptor and criterion could be interchangeably interpreted, nevertheless, for the clarification of the arguments and according to the traditional designation, the term descriptor will mostly be used to refer to the CIB approach, likewise, the term criterion will be applied when referring to ICoS.

The proposed conceptual framework, *Scenario-based sustainability assessment*, seeks to link a scientific concept to a systematic process by providing a structured comprehensive sustainable scenario analysis, so that information presented today can trigger informed decisions with outcomes in defined and consistent paths of the future visions. This methodological framework used for the Mixteca case study seeks to present transparent and traceable visions of the future scenarios which could be plausible - not necessarily desirable, present different and consistent portraits of the future, and quality criteria for scenarios (see section 2.3.2) that aim to be integrated into the whole method. In addition, the proposed method attempts to be transferable (see chapter 0) and be used in other energy transition assessments, and different geographic conditions. The focus of the social value of energy and its implications in the use of the proposed method could also become a significant base for future planning, and evaluate possible interrelationship impacts as in this case with the aim to alleviate poverty.

As the schematic representation of the process presented in Figure 25 shows, the conceptual framework of *Scenario-based sustainability assessment* involves two main approaches; ICoS, which provides the conceptual and normative aspect of the method through its sustainability goals and rules, and CIB that provides the operationalization of the concept through scenario analysis. An explanation of the integration approach follows.

The ICoS constitutive elements (global perspective, inter- and intragenerational justice, humankind perspective) are implemented into the three ICoS general goals (*Securing human existence*, *Maintaining society´s productive potential*, *Preserving society´s options for development and action*). These goals in turn are each subdivided into five rules (see Table 5 and further explanation in section 5.1.1). These first steps of the process constitute the conceptual and normative background of the method; the scientific concept is driven by experts - top-down (see section 2.2.3).

Thereafter, it has to be determined which of these rules apply or are relevant for the PV solar energy transition assessment in Mixteca. Next, the contextualization of the rules takes place. Further details on the analysis of the selected rules and their adaptation to the case in Mixteca are found in chapters 0 and 0. In this process, the context and specific local problems related to the environment in which the PV solar technology would be installed have to be considered in the interrelationship among all factors involved. A comprehensive analysis is then conducted between the factors influencing sustainability and their interrelation between all social aspects, but not only considering the technological side, as the social connections as a whole are equally relevant (see section 2.1.3).

Through literature and participative models (expert interviews, workshops) where a bottom-up approach is exerted, a selection of the most relevant criteria (inter)related to the solar PV transition in Mixteca were obtained, as well as indicators to be able to track their progress over time. The criteria-indicator system is chosen to represent the complex reality: the state of Mixteca's society, its social, economic and ecological connections, and their development and targets (see chapter 0). The selection of the criteria was performed in a way to cover all possible ICoS rules (see chapter 0).

The second approach introduced in this study, the CIB, analyzes impacts which are useful to describe plausible alternative future scenarios in order to deal with complexities and future uncertainties in a consistent and comprehensive way, and provide an improved knowledge base for decision-makers (see sections 2.3.2 and 5.2). One remark about CIB is that the concept does not intend to assess sustainability as a methodological goal. So, the states of the descriptors might present all future possibilities regardless of their (un)sustainability.

In order to build the future scenarios, in a first stage, the CIB requires a definition of the context, and a set of framework assumptions characterized by the system descriptors and derived by the selected method, i.e., literature and participative models, relevant stakeholders (experts) involved and orientated to the different aspects and problematics in the local region; these descriptors represent economic aspects, environmental factors, and social, political and cultural elements linked to the solar PV transition in Mixteca. This set of descriptors, along with their states and interdependences, is the basis for the scenarios construction. This is where a direct link between the ICoS and the CIB takes place. CIB and ICoS share the corresponding boundaries set by the system's context conditions and local problematics; given the common framework conditions, the criteria (and indicators) derived through the sustainable goals can be used as the descriptors required by CIB for scenario building. Then, under this suggested flow-process, the selection of descriptors / criteria can take place simultaneously, i.e., it is the same for both approaches, strongly shaped by the sustainability perspective through the adaptation of ICoS rules and the multidisciplinary experts participating in its designation.

A description of the elements that involve a solar PV energy transition in Mixteca is presented in chapter 0. The analysis of interdependencies might integrate this new impact network and identify new types of constellations / scenario arrangements. However, since the definition of the future uncertainties (states) does not necessarily involve a sustainability component, the CIB algorithm will provide scenarios that create impact network relationships within the consistent scenarios which result independently of the degree of sustainability. Using CIB provides consistent scenarios for ICoS to assess in a sustainability-related way. The advantage of this integrated alternative is that the context scenarios can be assessed in a more oriented way, i.e., using a defined sustainability framework, considering specific goals, defined targets and a common framework of context conditions. The way to operationalize the scenario process does not differ, except on the context integration. The corresponding experts can assess the interdependencies, moreover, the integration of the sustainability aspect with the context definition could lead to an improvement in the holistic approach and the interdisciplinary knowledge integration. Therefore, a systematic process for sustainability assessment using scenario building can take place. The integration of context conditions for CIB using the ICoS sustainability framework derives a new type of knowledge integration that could be useful as a method; a semi-quantitative model with qualitative impacts driven by societal implications to assess the sustainability degree of future scenarios.

In the Mixteca case, the result of the scenario-based process produced a series of eight socio-technical energy scenarios, where qualitative impacts show how the identified societal drivers act on the interrelationships between the societal and technical dynamics. A common understanding of the descriptors / criteria of the system is needed; both approaches share the same boundaries of the system and find a common mutual understanding.

Cross-Impact Balance analysis aims to generate a set of plausible scenarios through capturing the interrelationship of the key influencing factors (section 5.2). CIB does not aim to present a sustainable future but to describe a comprehensive analysis of a plausible future, while ICoS aims to assess this possible future in relation to sustainability. The integration of both approaches provides a structured method to describe and assess a possible future within a comprehensive sustainability assessment. Integration of knowledge from both approaches promotes interdisciplinary research, creating innovative views (Newell et al., 2005), in this case a vision of the future, in an attempt to include sustainability assessment. A comprehensive integration that promotes sustainable development is the aim, but simultaneously the challenge, of the joint approach.

The CIB-ICoS integration - in this study called *Scenario-based sustainability assessment* - for the solar PV transition in Mixteca, demonstrates that it works as a comprehensive approach with a broader overview of the human influence (social value) and interaction with different aspects of the system: social, economic, ecological, cultural, political and environmental impacts, and is useful for informed and sustained (although not necessarily better or improved) decision-making to alleviate poverty in the region. This combination is also useful to identify sustainability strengths and weaknesses, and to be able to elaborate further or provide special attention to those aspects in the desired direction, as provided by the scenario analysis.

The adoption of the integration of CIB-ICoS as method allows identification of the sustainability opportunities in the future desired path, as well as the risks of an unsustainable future; additionally, it also provides an overview of the (un)sustainable path to poverty alleviation. The practice of both approaches assists the facilitation of targeted advice by assigning quality improvements in those criteria whose future risks sustainable development under a certain path. This integration also shows to what extent the key sustainability aspects are addressed in the assessment. ICoS makes it possible to identify sustainable development opportunities by strengthening a sustainability-based approach in decision-making processes. The holistic approach of ICoS throughout this research suits the comprehensive analysis performed amidst CIB and its scenario array, where paths and strategies to poverty-reduction can be tailored.

The procedural steps of the *Scenario-based sustainability assessment* offer a comprehensive assessment of future scenarios, and the combination affords reflexivity, as the components of the process underlying the scenario assumptions must be articulated, thereby enabling their analysis. Scenarios are employed whenever decisions must be made under conditions of uncertainty. For Mixteca, the articulation of societal, economic, political, and cultural scenarios from CIB, combined with the sustainability goals from ICoS, is a helpful systematic approach with a scientific-based assessment for sustainable scenario identification. CIB is an exploratory scenario method tempered by theoretical or empirical judgments of how the descriptors' states interrelate to constrain or promote each other. The sustainability assessment from ICoS has been developed as a scientific systematic process that allows us to translate sustainable development in Mixteca into tangible decisions and subsequent actions in the present. Hence, the sustainability assessment might contribute to articulated shifts of actions that can enhance the potential to change fundamental assumptions and values that bring a direction for poverty alleviation in Mixteca resulting from a solar PV transition. This would represent a shift in policy discourse with desired practical reactions. The potential contribution of the integration of CIB and ICoS could also reach and influence not only policy, but also other stakeholders (NGOs, private investors, cooperative members or the inhabitants themselves) to provide scientifically-supported anticipatory decision alternatives that promote sustainable development in the area.

The integration and implementation of both approaches can display a consistent and solid direction as to whether a specific future scenario could (not) be sustainable compared to the rest of the scenarios. This sustainability feature cannot be attained per se under standard CIB results. ICoS assists on bonding the criteria with a sustainable component, providing the stakeholder with future alternatives. Nevertheless, despite this array of scenario alternatives, the *Scenario-based sustainability assessment* will not be able to provide answers as to why a certain scenario performs better or worse in a distant future. The stakeholder analyses would be required. Notwithstanding, the combination of both approaches allows a focus on future consistent transformation strategies, whether successful or not; that depends on the decisions (or lack of them) taken in the present by the different actors involved. Adding ICoS to the CIB analysis provides further benefits to this comprehensive assessment towards transdisciplinary assumptions across multiple sectors; the CIB structure is able to infuse and benefit an alternative future with its predictive quality, while ICoS assists with targeting specific goals on criteria, and foreseeing how the alternatives perform in the future regarding sustainability.

Some remarks on the use of this methodology that can impact the assessment results are:

1) the type of information: if most of the information used during the analysis is qualitative, then the interpretation of the interrelationship between descriptors / criteria within the future scenarios are dependent on the experts' interpretation; this could be seen as a limitation, since the group of experts and its selection impact the judgments.

2) Stakeholder selection: if a limited group of stakeholders participate, or if their areas of expertise are not fully covered, the assessment will be affected by the (substantial or reduced) quality of the judgments, impacting the results. The integration of both approaches provides additional insights that could allow better-grounded (judicious) decisions. An open point of discussion in this respect would rest on the type of decisions or judgments, however the scope and extent of decisions are not evaluated in this study since it falls outside its scope.

3) The sustainability results are dependent on the scenario outcomes provided by CIB: as explained in section 5.2, since CIB does not intend to predict the future, this *Scenario-based sustainability assessment* is not a forecasting tool, hence assessment of future scenarios depends on the impact relations of the judgments. If these change, then the future scenarios would also change, consequently the assessment is also impacted; a comprehensive assessment is based on a comprehensive description of the future.

The *Scenario-based sustainability assessment* could provide a suitable opportunity to allow the sustainability role to be included within the transdisciplinary collaboration and enhance the participation of stakeholders and direct beneficiaries in the area to develop strategies that link present decisions with a future desired sustainable scenario, or avoid undesired unsustainable scenarios addressing uncertainties to facilitate more informed decision making.

Regarding the fourth research question, "How to develop a consistent framework to conduct a comprehensive scenario assessment?" (see chapter 0), the presented analysis contributes to the answer. Given the systematic approach, the framework can be adapted to specific circumstances and cases due to the procedural and general guidance, which is useful in transdisciplinary processes. The systematic procedure would allow a step-by-step process and guidance on how to derive the scenario assessment and adapt it to different contexts. The combination of ICoS with CIB makes it possible to assess how the (un)sustainable future might look, in addition, through the identification of constraints, it would be possible to analyze the consequences of the different transformation pathways provided by the scenario analysis.

"Seven social sins: politics without principles, wealth without work, pleasure without conscience, knowledge without character, commerce without morality, science without humanity, and worship without sacrifice"

— Mahatma Gandhi (1925)

6. Constituents and attributes

This chapter 0 along with subsequent chapters 0, 0 and 0 belongs to Part 4 of the dissertation; the application of the method and results presentation (see chapter 0).

The definition of the factors that would influence a transition to a PV solar system in Mixteca is a central part of the method, since these elements are the base for both the scenario analysis and the sustainability assessment (see Figure 25). Hence, the adequate definition of criteria / descriptors (see section 5.3) is of utmost relevance. The following sections provide the list of criteria / descriptors along with their future states.

In order to achieve the sustainability goals provided by the rules of the Integrative Concept of Sustainability (ICoS) (sections 5.1, 5.3) a set of descriptors/criteria need to be identified to assess the sustainable performance of the solar PV system. These elements are needed to define and frame the social, economic, political, cultural and environmental context and the probable future evolution of rural Mixteca. The identification and selection of descriptors was conducted through the data collection explained in the first step of the Cross-Impact Balance (CIB) (see section 5.2).

This process included a preliminary selection of thirty descriptors identified through literature review. This list was narrowed down through the discussion with experts and researchers. Finally, during a five-week field trip to Mixteca in July-August 2019, interviews were held with a range of stakeholders. As a result, eighteen descriptors / criteria were selected to frame Mixteca's case system. The information provided by the experts was complemented with desk research. With the help of the different actors involved in the descriptors / criteria selection process, the states of each descriptor were also identified, as described in the CIB process in section 5.2.

Table 7 shows a summary of the actors involved in the definition of the context conditions in the region.

Table 7. Stakeholders interviewed for Mixteca solar PV energy transition research case.

Type	Affiliation	No.people interviewed
Community	Community visits Mixteca-Ayotlicha	9
	Community visits Mixteca-Ayoxuxtla de Zapata	10
	Community workshop with representatives from Proyecto de Desarrollo Territorial (PRODETER)	25
	Escuela Normal Experimental Huajuapan, Oaxaca	1
Consultant	Nedwork Foundation-Gender, Energy and Environment (GENEN)	1
	Red Mujeres en Energía Renovable y Eficiencia Energética (REDMEREE)	1
	SER Grupo Consultor S.C.	1
Cooperative	Cooperativa Tosepan	1
Government	Comité Técnico de Cambio Climático del estado de Oaxaca	1
	Consejo Superior del Cooperativismo de la República Mexicana	1
	Government representative in Mixteca-El Platanar	2
	Proyecto de Desarrollo Territorial (PRODETER) and Comisión Nacional de Áreas Naturales	3
International cooperation	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)-Mexico	1
NGO	"Ayuda en acción" chapter Mexico	1
	"Ayuda en acción" representative from Spain	1
	Agencia Española de Cooperación Internacional para el Desarrollo (AECID)	1
	Centro de Desarrollo Integral Campesino de la Mixteca (CEDICAM)	1
	Centro de Innovacion Integral para el Desarrollo Rural Kukoj S.C.	2
	Proyecto para los Niños Acatecos A.C- Child Fund Mexico	1
Private company	Alternativas y procesos de participación social A.C.	1
Researcher	Benemérita Universidad Autónoma de Puebla (BUAP)	2
	Centro de Investigaciones y Estudios Superiores en Antropología Social (CIESAS)	1
	Colegio de Postgraduados (COLPOS), Gobierno de México	2
	Consejo Nacional de Ciencia y Tecnología (CONACYT)	1
	Instituto de Energías Renovables (IER)- Universidad Nacional Autónoma de México (UNAM)	4
	Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)	1
	Universidad Autónoma de Guerrero	1
	Universidad Nacional Autónoma de México (UNAM)	1

Given that Mixteca is immersed in the state of Puebla, which is subjected to laws and regulations that apply within the country, some aspects would necessarily consider the state and national context, despite the fact that the local perspective prevails. The descriptors / criteria selected and presented here provide the context to understand the factors influencing a transition to a PV solar system in Mixteca. Many of these context conditions were introduced in chapter 0, where the status quo of the area was detailed. Following their definition, the future states of these descriptors / criteria are also introduced. The assessment considers a selected timeframe of thirty years, or more precisely by 2050, given that the conditions for a solar PV transition represent a long-term process that should be planned with enough time in advance so that decisions could be carefully tailored. The following paragraphs present the eighteen descriptors / criteria (A - T) selected and their states.

A. Emigration. Over the decades, Mixteca's population has been affected by emigration, which has been traced mostly to North Mexico and border cities, and across the border to work in commercial agriculture and low-paid jobs in factories in the USA (Durand et al., 2016). According to the most recent census, 23% of the population originally from Mixteca currently lives in other states in the country (author's calculation per data from (INEGI, 2020a)). This figure represents only the population within Mexico. Initially, mainly men left home, sending income to families left behind in the area. The following future trends for the emigration phenomenon are foreseen to take place in Mixteca: **State 1**: return emigration; given that involuntary as well as voluntary return migration has taken place in recent years, it is expected to continue in future trends, especially if economic conditions worsen in the USA. **State 2**: permanent emigration with bond; one main aim of emigrating is the possibility to obtain a job and secure income, which would serve to sustain a family and / or relatives left behind in Mixteca (the bond) through delivery of remittances. Remittance flows have been increasing over the years, so the possibility for permanent emigration in order to secure an income to keep the bond with their place of origin is a future likelihood. **State 3**: permanent emigration without bond; some emigrants - e.g., children of emigrant parents born abroad - do not feel integrated with their community of origin, and sometimes suffer stigma and discrimination when retuning to Mixteca; they consequently look forward to a permanent emigration without bonding to their communities of origin.

B. Ethnic identification. Ethnicity is a distinctive factor in Mixteca society. Indigenous people are the holders of a subjective sense of belonging, such as culture, identity and language. Ethnicity is often a major source of social cohesion as well as a social conflict. Indigenous people hold their own diverse concepts of development, based on their traditional values, visions, needs and priorities (Caballero, 2012). Indigenous groups often lack civil political representation and participation, as well as access to social services; they endure marginalization, discrimination and poverty. They strive for recognition of their identities and their lifestyle without the negative stigma these are subjected to. They form at present non-dominant sectors of society, and are determined to preserve, develop, and transmit their ethnic identity to future generations as the basis of continued existence as an ethnic group, in accordance with their own cultural patterns, social institutions and even legal system (Hernández Rodríguez et al., 2009). The following future states for ethnic identification are sketched: **State 1**: low ethnic identification; the discrimination the native population is subjected to due to their native language, skin color, traditional dress as well as habits and customs make the people aware of their vulnerability, since from an early age they learn that the less identified they feel with their native roots, the easier it would be to blend in and be accepted outside their community. **State 2**: high ethnic identification; a sector of the native population, e.g., adults and the elderly, are aware of their heritage from a great civilization in ancient times and are proud of their roots, they continue to live through their customs and habits, speak the native language and wear traditional dress. **State 3**: pluricultural; native inhabitants have learned to cope between two environments, they understand their customs and traditions, are bilingual (native language and Spanish), and have reached a degree of acculturation in the non-native environment that can live in either “world”.

C. Education. Education levels differ among native and non-native populations, as well as within generations in the area; adults and older generations have little or no formal education. One of the factors contributing to a low education level in the area is the limited provision of instruction in native languages and a poor structured process, even though the Mixteca language is the third most spoken indigenous language among school-age children (INEE, 2016). Upper secondary education, as well as high-school institutions, promote education in the country’s main language (Spanish), and not in the mother tongue, which restrains accessibility to indigenous inhabitants. A low-income population is related to low- or no education level. Current earnings obtained through street vending, construction work, handcrafts, palm weaving and subsistence farming, that require little or no formal education, guarantee they remain within the poverty cycle. The following future states are envisaged for education in Mixteca. **State 1**: less than 5 years; a sector of the population will continue to be illiterate, despite governmental efforts to enforce basic education; institutional challenges as well as individual limitations might keep the population at a low education level; in other instances, parents would require assistance from their children in immediate income-generating activities or household chores and would prefer not to send their children to school. **State 2**: from 5 to 9 years; a sector of the population will try to reach a minimum level of instruction; their first immediate goal is to finish secondary education in the aim to get better qualifications for a formal job in the future. **State 3**: more than 9 years; efforts are made to earn a higher education by a small sector of the population who would need to emigrate outside Mixteca to pursue a higher level since there are no higher education institutions in the region.

D. Source of income. Remittances are an important source of monetary flows correlated with emigration, mainly to the USA. Mixteca has a 13% share of Puebla State's remittances, with around 226 million USD received in the area. The main uses of remittances are for food, clothes, to pay debts and home improvements (Consejo Nacional de Población and Fundación BBVA, 2019), which means that a family's income in Mixteca is not enough to cover basic needs. Self-employment such as subsistence agriculture, gathering of wild fruits, palm weaving and livestock are the most prominent activities to earn a living. The informal economy is also present in urban areas such as street vendors or handcraft products, whose skills require only basic education to make a subsistence living, ensuring once again to continue within the poverty cycle. The following states have been identified for the future scenarios in the area. **State 1**: labor. It is desirable that the primary source of income is labor from their own free designated activity; it implies a formal (self) employment with social benefits (health insurance, pension and social benefits) and not within an informal economy which does not contribute to GDP or provide benefits to the workers. **State 2**: remittances; given the area's high dependence on remittances over the decades, plus the future uncertainty, the provision of income through remittances is a feasible state for the future in the area. **State 3**: remittances plus labor; a first step into a sustainable future would be a lower dependence on remittances; this scenario could take place once employment in the area starts improving or opportunities to make a living are available.

E. Basic services access (water, electricity, drainage). In this study 'basic services' refers to basic sanitation (80 % of the population has access), water supply that needs to be collected to their homes (63%), and electricity access (93%). See chapter 0. Only 54% of the inhabitants are covered by all three basic services in the region (INEGI, 2020a). Two-thirds of the population in Mixteca live in rural communities of less than 2500 inhabitants, where access to basic services is not guaranteed. In addition to the low access to basic infrastructure, the quality of the provided services is meager. The water service quality is intermittent and not drinkable; electricity, currently supplied through fossil fuels generation, is delivered under poor efficiency, and availability and reliance are not assured, hence, electricity cannot be used for productive uses. The following states are foreseen as plausible for the future scenarios in Mixteca. **State 1**: no access to any services; despite its pessimistic prognosis, given the decades of poverty and lack of investment in the area, the possibility that a sector of the population remains without access to any services is feasible, although not desirable. **State 2**: partial access to services including water; this state considers the availability of running (piped) water and either electricity or drainage, but not both. Since the statistics show a high connectivity to the electricity grid, it is mostly likely that connection to the grid may be provided, although quality of the service is under discussion. **State 3**: partial access to services including electricity; in the case where a solar PV transition took place in the area, the first improvement in basic services access would be in electricity provision, aiming to be used for productive purposes. **State 4**: access to all services; this would be the aim of a sustainable future - full coverage of basic services to all inhabitants.

F. Population acceptance of renewable energy plans and participation. The success of a solar energy transition depends on the acceptance and participation of the whole society in

Mixteca in the decisions regarding all processes along the transition. It has been documented that when local communities are included in the decision-making process, placing them at the center of the solutions to challenges in the energy transition, a sustainable development could be reached (Biswas et al., 2021a). To such an end, participatory approaches are needed that strengthen bottom-up decisions. One mechanism to promote acceptance and participation is to address consumer (co-)ownership of the solar technology, promoting access to all members of the community, including marginalized groups. The solar transition involves significant social and behavioral transformations in the local communities: awareness of the future benefits, improvement in collective wellbeing, to potentially retain control as an organized self-sufficient community in energy-related concerns; gain empowerment to drive further project developments and become (as a community) a possible future supplier of solar energy to nearby regions. The active participation of inhabitants in Mixteca and engagement in community energy proposals and projects could trigger a smooth energy transition, as well as community self-determination, including local government development initiatives. The community's participation would not be limited to merely consumers but rather to a producer role or "prosumer". An evolved degree of participation is desired for a sustained future. As a result, the following states could be foreseen. **State 1**: poor community organization; the region is not able to create a resonance capacity directed to a successful transition, either a lack of information or awareness impedes acceptance, or inhabitants are reluctant to participate (which might be due to e.g., a lack of trust, fear of consequences, unjust distribution of benefits) **State 2**: limited to labor; the population is motivated and eager to take part in the solar transition but due to their limited economic resources, they can only take part by providing their labor, in a comparable way to how provide a workforce for communal projects under the *Tequio* scheme (see chapter 0). **State 3**: support includes economic contribution; inhabitants are fully engaged in the solar PV transition and despite their limitations, they make an effort to take part in a prosumer role and contribute with economic capital to the technology transition.

G. Job and earnings. Nearly one-third of the population in Mixteca is economically active, nevertheless, about 85% of the working population earns less than the minimum wage (CONEVAL, 2018b). Not only is their income meager, but growth opportunities are also scant, and sometimes unsafe working conditions also prevail. Even though there have been some efforts from stakeholders to provide employment sources from maquila factories, the underlying issue is unfair wages, and the disparity between the income generated at sale and the labor cost of the product. The added value is distributed among a few people who are the owners of the capital, and is not distributed to improve the prosperity of the local community. Inhabitants in Mixteca where employment opportunities are scarce, low-waged, or precarious, experience greater economic insecurity, whose consequences are seen in poor health conditions, low quality housing and low food quality. Moreover, they might also have reduced ability to access education, hence their future employment opportunities decrease, turning into a vicious circle. The future for Mixteca regarding jobs and earnings looks as follows. **State 1**: stable jobs and minimum wages or below-minimum wages. The possibility for an employment opportunity under stable conditions with social security and health insurance is foreseen, however, the minimum wage or below the minimum wage (likely justified as acceptable for a non-full-time employee) are real possibilities. **State 2**: stable job above minimum wage; this is a very much desired state and is the only sustainable alternative for development in the area, or (self)employment possibilities with a fair wage promoting a secure income from their own work. **State 3**: no secure job and below-minimum wage; this is the current status quo which is still a possibility to take place in the future if adequate measures are not taken to promote employment or income-generating activities in the area; this state foresees the continuation of the poverty cycle in the region. **State 4**: no secure job and above-minimum wage; temporary employment or seasonal opportunities might also bring instability where income could be generated above minimum wage but only during certain time periods, a challenge is to carefully manage earnings during times when no income is available; it also brings uncertainty since given the scarce opportunities, only a few people get the chance for employment.

H. Governance uncertainties. Mexico's present political landscape shows acute uncertainties for the future decades. The political arena has been characterized by a new degree of visibility but still lacks accountability. For this reason, there are not local trustworthy statistics, so national assessments provided by international organizations will be used as a reference in this analysis. The poor assessment of institutional capacity shows an acute deficit for security, public sector performance, and transparency. Mexico scored 98th - out of 141 countries - in the most recent ranking (World Economic Forum, 2019). The population has become increasingly aware of the corrupt dealings between Mexico's narrow oligarchy of millionaires and the political class. Social inequality and stagnant poverty levels have increased in the last two recorded years, breaking the pattern of slow but consistent historic decrease (CONEVAL, 2020). Mexico holds one of the lowest scores in Government trust, where only 17% of the population trust the civil service, 15% trust their national parliament, about 25% trust the police, and 17% trust their government (OECD, 2021). These are signals of poor performance and commitment on behalf of the public administration towards its citizens; these numbers show a wide gap between the population's expectations and the government's achievements, which leads to high governance uncertainties, or could also indicate a weak democracy. The current government's measures have been continually adding regulatory uncertainty to an already-opaque context, directly affecting projects under development and in operation. The future might (or might not) change direction in 2024 when the next administration comes into power. The following states have been identified for the future governance: **State 1**: low uncertainties; future administrations might improve the status quo, so trust in the government can be regained and actions are addressed to fulfill policies and the loss of rule of law. **State 2**: strong uncertainties with growth; during past decades the country has endured high governance uncertainties but politics have addressed economic growth; even though not much of the wealth generated has reached Mixteca, local government has received a budget from the state government where funds were available for community infrastructure, and although corruption played a role in its distribution, minor growth was still a factor. **State 3**: strong uncertainties without growth; it might be that the current status quo could worsen in future decades, high levels of inequality and poverty would persist as a result of the weak government performance.

I. Governmental policies for an integrated energy system. Mexico's current government has redirected the energy sector, in a way which seems to oppose previous reforms, by strengthening and favoring state-owned energy and electricity suppliers PEMEX and CFE over the private sector (Flannery, 2021a). The present administration seems also to backstep on the committed climate goals, causing uncertainty for private investors who are the main drivers of clean energy production. The cancellation of the green certificate auctions in 2018, proposed policies to change dispatch criteria in 2019, and uncertainty over the newly-proposed electricity market rules and regulations in 2020 and 2021, have all reduced investor confidence. New renewable energy developments have been paused, and new permits are no longer granted. Some of the projects are in dispute, US and Canadian investments alone are estimated in 30 billion USD in Mexico's energy infrastructure (Reuters, 2022). Projects in later stages continue despite the delays by court processes that plaintiffs have to withstand because of the government's failure to comply with the agreed investments terms. Under these circumstances, analysts believe Mexico will miss its committed target of 35% of electricity generation from clean energy sources by 2024 (PRODESEN 2021-2035; Deign, 2020; Flannery, 2021b). The present government insists on boosting fossil fuels expenditure through the construction of a new oil refinery, solar PV investors show a slowdown linked to increasing political and regulatory uncertainty due to the unfavorable shift in policy from Mexico’s government, and new measures do not encourage private investment in the solar (and renewable) electricity sector. Investors face also the challenges of securing financing and long-term power-purchase agreements due to the risks associated with regulatory uncertainty (Wood Mackenzie, 2020). The government has increased fees for self-supply projects and has refused to invest in energy transmission infrastructure, including planned upgrades that would have allowed rich regions (wind and solar mainly) to add significant GW of new generation to the grid. **State 1**: restrictive policies on new energy systems; it seems the current governmental policies are not likely to return to supporting renewable sources, nevertheless the uncertainty over what direction the following government(s) will lead, is a legitimate concern for solar energy investments and their long-term future. **State 2**: supportive policies on new energy systems; after the current administration’s term ends in 2024, the possibility that a new government could boost renewable energy policies so that the solar energy developers go back into the market is a potential turnaround. Easing legal, regulatory and electricity market frameworks could enable rich solar regions such as Mixteca to attract investments and scale-up solar supply.

J. Investments in energy research. Energy access is a condition of societal development to satisfy basic needs of daily life. A sustainable development relates to the use of renewable sources of energy, and for Mixteca, solar energy would provide immediate benefits, such as electricity provision for basic and productive uses (with more reliability and efficiency than the current one based on fossil fuels), as well as clean cooking facilities. Considering the importance of the development of future activities in Mixteca (e.g., education, capacity building, water provision, health care, farmland irrigation), investment in solar energy research is a vital support to “ensure a future affordable, reliable, sustainable and modern energy for all” - UN SDG7 (United Nations, 2022), and at the same time build a sustainable future while tackling environmental issues such as climate change, soil erosion and air pollution. One measure of commitment to the development of new energy technologies is public and private investment in energy research. A low level of investment means not only a concern today but for decades to come. Encouraging technological changes in the energy sector conveys a technological economic driver. Public investment in energy research is an important measure of a society’s engagement in a resilient and prosperous future. In the Mixteca case, it would mean a future decent life profiting from the natural resources at hand: solar; and the possibility to become a solar energy supplier to other regions. Hence, investment is a precondition for sustainable growth and development. The following two alternatives for investment in energy research for Mixteca can be outlined: **State 1**: low investment or none; despite the fact the region is rich in solar resources, multiple additional factors need to be considered before an investment in energy research can take place: including the availability of basic services, communication means, an upgrade of the grid, so investment in energy research involves pre-conditions that need to be considered by the investors. There is a possibility that if the conditions for the investment are not convincing, this will not take place. **State 2**: high level of investment; In contrast to state 1, the future benefits of energy research investment in the area may outweigh the challenges so that investment can succeed.

M. Cooperation between government, private investors, NGOs. The collaboration between different stakeholders, namely government, private investors and NGOs, improves the design, development, financing support and development of a project, in this case, a solar PV system in Mixteca. A good interaction between these entities and the local communities offers an opportunity of using local resources, diverse thinking and promoting reliance in the process. The different perspectives and experiences from these entities enables outcomes that could make it more assertive in meeting societal needs (Feinholz-Klip et al., 2009; Frow et al., 2015). The importance of the interplay lies in the expertise of each party: the government can plan the solar PV energy transition in Mixteca, NGOs can provide the assistance needed with the local communities and involve social concerns, e.g., population acceptance and participation in the transition; private investors through their expertise could identify circumstances or events that might affect / threaten the investment (regardless of whether the population is the prosumer of the economic capital) and provide support for the infrastructure needed around the main investment, e.g., electricity grid, roads, communication services, basic services provision and so forth. This interplay also creates shared social responsibility and understanding of key uncertainties, and a basis for more coherent responses to major long-term challenges (OECD, 2021).

The different and frequently divergent interests of the actors currently interacting in Mixteca are barriers to exercising free, objective decision-making processes in favor of a beneficial interaction. The lack of commitment to reconcile these interests - mostly about economic power - in favor of the general population and the most vulnerable sector, has been the main impediment to development and a sustainable future in Mixteca. The forces of power in the region are usually aligned towards those with the most economic or political influence, setting aside the population's needs or environmental requirements. These barriers include a central short-term orientation with all actors involved looking forward to "immediate" results. It is desirable that the involved parties such as government, private investors and NGOs reach an agreement to create the necessary conditions to implement different responsibilities to succeed in achieving diverse socio-economic related challenges. The following states have been identified: **State 1**: nonexistent or low; the cooperation between the government, private investors and NGOs would be insignificant, the population will the most affected agent, poverty in the area will persist. **State 2**: existent or good; a good interplay between the different actors could be foreseen. **State 3**: excellent; this is the ideal state for a sustainable future in which all interested parties focus their efforts on the sustainable development of the region.

N. Added Value creation from the renewable energy sector. In addition to the mitigation of environmental effects caused by the use of fossil fuels, sustained economic impacts can be obtained from the switch to renewable energies. Mixteca's possible use of PV solar resources could contribute to job creation in the area, upgrading capacity-building, and creating a positive impact in the labor market. The added value from renewable sources prompts education, training and research related to human and knowledge capital. Other additional economic variables that could positively be impacted by the transition to solar energy, in addition to employment, are investment, trade, commercial activity, and tax revenue whose effects could in turn bring GDP growth (Bulavskaya and Reynès, 2018). This added value can support the productive potential of the local society in Mixteca. Currently, uncertainty and poor performance of the government institutional capacity have caused tensions among private investors, reducing stakeholders' expectations and willingness to invest, hence impeding added value creation. The following two states could take place: **State 1**: nonexistent or very low; the last decades as described in Mixteca's status quo have seen a very low level of added value from economic activities, if the (local) government does not make an effort to promote activities supporting production of solar energy, nonexistent added value will persist for coming decades. **State 2**: existent or good; if capacity-building, promotion and production of solar energy are supported in Mixteca, an increase in added value could take place.

O. Financial market in the rural economy. The vast majority of inhabitants in Mixteca lack access to formal financial services, moreover, rural communities do not have a point of service for residents to process basic transactions. The World Bank shows a correlation between financial inclusion and poverty alleviation: as people gain access to financial services, they can save money and start building a credit profile, leading to the potential for loans, and thus grow (World Bank, 2020). Among the factors impeding inhabitants' access to formal banking are insufficient funds, account costs, distance, lack of documentation and distrust. A significant number of the financial service providers which are available operate as unauthorized, unregulated savings and credit entities. These entities offer less restrictive conditions and provide loans with high interest rates. Due to their irregular activity, they are prone to disappear along with the savings. The following states have been envisioned for the future in Mixteca: **State 1**: limited access to the formal financial market; if no support to finance productive activities takes place, the status quo in Mixteca could persist in the future. **State 2**: access to informal financial market; due to a lack of access to regulated banking institutions, the available alternative would be to keep paying high interest rates for meager loans, mostly used to cover basic needs without the chance to invest in capital assets to promote development. **State 3**: no access to formal or informal market; nonexistent opportunities to grow, and no employment or income opportunities turn into the most unsustainable status of financing which perpetuates the poverty cycle.

P. Legal system. The 67th Session of the UN General Assembly adopted a resolution in which development, poverty and the rule of law were recognized as closely interrelated and mutually reinforcing. This declaration establishes that "the advancement of the rule of law at the national and international levels is essential for sustained and inclusive economic growth, sustainable development, the eradication of poverty and hunger and the full realization of all human rights and fundamental freedoms" (UN General Assembly, 2012). Despite a strong legal framework, Mexico's legislation is not effectively enforced. Among the factors that measure the efficiency and effectiveness of the legal system is the perception of corruption. Corruption undermines human rights and contributes to a democratic decline. In general, organized crime, corruption, and human rights violations pose severe challenges to Mexican governance. The latest corruption perception index from an international organization shows a score of 31 points on a scale of 0 to 100, where 100 stands for lack of corruption and 0 highly corrupt (Transparency International, 2022). The national perception index scores higher, close to 53, although the methodology to calculate it is different and the index is not updated yearly (INEGI, 2019). Nevertheless, both scores show an urgent need to fight against corruption. In spite of the government´s anti-corruption rhetoric, major cases over political and electoral (ab)use in the country go unpunished. Corruption, and the low efficiency of the legal framework in settling disputes, present a significant risk for all-sizes of companies operating in Mexico, as well as for the general population. The World Economic Forum evaluates Mexico as the second lowest score (among 38 countries) at ensuring public institutions embed strong governance principles and a long-term vision and build trust by serving their citizens (World Economic Forum, 2020a). Statistics show that bribes and irregular payments are frequently paid in the process of obtaining public services. Basic service access, construction permits and licenses, are negatively influenced by corruption (INEGI, 2019). There is a need to ensure public institutions embed strong governance principles and a long-term vision and build trust among their citizens by being a good service provider. **State 1**: law enforcement; the most desired state for a sustainable development in which the rule of law exists and strong institutions back up the legal system at all levels, national, state and local. **State 2**: aggravated; a pessimistic overview that could take place if effective measures to correct a lack of solid institutions that enforce the legal system are not taken. **State 3**: not effectively enforced; some efforts are made to enforce the rule of law, however, these are not enough to eradicate corruption or to strengthen institutions that promote a solid legal framework.

Q. Climate change. Potential consequences of climate change in Mixteca include increased frequency and intensity of heatwaves as well as droughts. Using modeling projections for future climate scenarios and based on the Intergovernmental Panel on Climate Change (IPCC) guidelines, the Mixteca area could see the replacement of semi-arid vegetation by arid vegetation. Moreover, by 2050, 50% of the scarce agricultural lands are likely to be subjected to desertification; biodiversity in natural ecosystems will be at risk. Precipitation trends for the summer season are forecasted to decrease -0.86 mm/day; projected temperature increase in the region of about 2°C is estimated by 2040 (Gobierno del Estado de Puebla, 2011). One mitigation strategy that contributes to fight climate change is the transition to renewable energies and displacement of fossil fuels. The Mixteca region is rich in solar resources and could contribute to the solar energy production of the state, and thus to the national share; not only on a self-supply basis. But eventually, if Mixteca's solar generation potential is effectively harvested, the region could become a considerable supplier of solar energy to the state or surrounding urban areas. **State 1**: high impact; if the transition to solar energy does not take place, (in addition to increased energy consumption) and no additional measures are taken to mitigate climate change impacts, these will be high. **State 2**: low impact; Mixteca's transition to solar energy could positively contribute in a joint effort to ameliorate the impacts on climate change.

R. Environmental effects on population. Climate change may affect the population in Mixteca through a range of pathways, for instance, it is likely that the frequency of heatwaves will increase not only heat-related human mortality in the region but livestock as well. Rural communities may be displaced or pushed to re-integrate to a semi-urban area. Certain models project a substantial increase in the number of people at risk of infectious diseases such as dengue, due to changes in the geographical limits of transmission or in the distribution of vector-borne diseases. The overall balance of effects is likely negative and the population in Mixteca is likely vulnerable to the adverse effects if appropriate measures are not taken. Several aspects causing environmental effects on the population are beyond Mixteca's control, nevertheless, there are some trigger elements that can be handled, monitored and followed-up to avoid major negative consequences in the future. Among these are air emissions such as particulate matter (PM) and ozone (O_3) which can represent up to 50% of the total concentration of particles in the air (World Health Organization, 2006), and are potentially harmful to the environment and human health. The principal source of PM and O_3 are related to fossil fuels use, which is the reason their monitoring and control becomes important, as in cases like Mixteca, where these elements currently do not receive attention, they could become an issue in the future, hence, its control deserves considerable attention before a problem arises. Ozone concentrations tend to be higher in rural regions adjacent to urban centers due to the chemical reaction with nitric oxide and can be transported long distances in the atmosphere, therefore it is considered a transboundary problem (World Health Organization, 2006). This phenomenon, if monitored and correlated adequately to nearby urban areas close to Mixteca, could be a useful measure to assist in reporting issues related to other problematic regions. The following states have been identified for the future in Mixteca: **State 1**: high impact; if appropriate measures are not taken to monitor and tackle the causes of the environmental effects on the population, the outcomes will have a high impact on the inhabitants of the area as well as the environment. **State 2**: low impact; thoughtful and dedicated decisions to promote health and care for the population would allow a lower impact of environmental effects on the population.

S. Women's empowerment. The literacy gap between the male and female populations is contrasting, i.e., close to 18% of the women in Mixteca are illiterate compared to 12% of their male counterparts, and these figures show the effects of low schooling attendance in the female population from an early age. Women's work in Mixteca is associated with unpaid household care activities (among these, are care of children and the elderly), on which they spend three times as much time as men. Statistics show that nationally only 47% of women are in the labor force, and, significant gaps in wages and income show how women are less valued than men in the workplace (World Economic Forum, 2020b). Nevertheless, this descriptor goes beyond increasing literacy or gender equality. A woman in Mixteca who has been directly affected by her emigrated partner or family, has carried not only the household burden but has also managed to make a living by herself. She has faced land decisions (to harvest, to manage workers, sell harvest or even land), is responsible for children's welfare and in many cases is entitled to make important decisions in the administrative positions in her surrounding community. Educating and empowering Mixteca women appropriately in the benefits and use of solar energy and providing the pertinent power to take decisions for the community could improve the potential to reach an adequate and informed decision to switch to this type of energy. The following states could be foreseen in the future of women's empowerment. **State 1**: limited or no empowerment; the efforts of Mixteca's women will remain undervalued and marginalized, their leadership and decision-making in solar energy projects are highly likely to be unrecognized. **State 2**: full / attained; women's empowerment has increased their freedom to decide, participate and influence decisions at the community level, including those related to the management of the energy sources; this is a strong recognition of women's value and one step further into sustainable development. **State 3**: partial; partial recognition of women's productive role is meaningful, nevertheless, the community should strive to unleash women's potential in all aspects, economic, political and societal.

T. Community organization. Collective actions are fundamental to cope with individual problems, and fundamental to social life. Community organization entails a social response to individual and collective needs such as energy; the management of natural resources entails decisions that could benefit or hinder the community's future, hence, an adequate organization is important. In Mixteca, this exists as a commitment towards the community, *Tequio* (see chapter 0), promotes social participation, hence, the degree of commitment within native communities in Mixteca is usually high. The organization of community work is a link that keeps rural society integrated; it is not only an economic function, but a well-recognized social bond whose meaning is as important as family relationships, festivities and religious rituals (Tobón, 2017). This means that each member of the community contributes to the community benefit in several ways. This is also the basis of a cooperative system through which new projects can be undertaken for the benefit of the entire community. The following future states have been identified. **State 1**: poor community organization; a lack of collective involvement could turn into poor support to improve local infrastructure, reducing social network interactions to an individualistic overview to deal with issues, not the suitable alternative for future community development. **State 2**: limited to labor; inhabitants are committed to participate in community projects but given their insufficient budget, their contribution is restricted to their labor. **State 3**: support includes economic contribution; inhabitants are convinced their full participation in communal activities for the collective benefit highly promotes sustainable development, hence, their efforts include economic support despite their meager income.

The identification and selection of these eighteen factors addresses the first research question introduced in chapter 0: "What are the socio-economic factors which could promote a sustainable performance in Mixteca by transitioning to solar energy technology?" In this chapter, the eighteen descriptors / criteria were introduced as defining elements framing the social, economic, political, cultural, environmental context and probable future evolution of rural Mixteca. Table 8 provides a summary of the descriptors / criteria and their states, as presented in this chapter.

Table 8. Descriptors and states identified for Mixteca.

Descriptor	State 1	State 2	State 3	State 4
A. Emigration	A1 return emigration	A2 permanent emigration with bond	A3 permanent emigration without bond	
B. Ethnic identification	B1 low ethnic identification	B2 high ethnic identification	B3 pluricultural	
C. Education	C1 less than 5 years	C2 from 5 to 9 years	C3 more than 9 years	
D. Source of income	D1 labor	D2 remittances	D3 remittances plus labor	
E. Basic services access (water, electricity, drainage)	E1 no access to any service	E2 partial access to services including water	E3 partial access to services including electricity	E4 access to all services
F. Population acceptance of renewable energy plans and participation	F1 poor community organization	F2 limited to labor	F3 support includes economic contribution	
G. Job and earnings	G1 stable job and minimum or below minimum wage	G2 stable job above minimum wage	G3 no secure job and below minimum wage	G4 no secure job and above minimum wage
H. Governance uncertainties	H1 low uncertainties	H2 strong uncertainties with growth	H3 strong uncertainties without growth	
I. Governmental policies for integrated energy system	I1 restrictive policies on new energy systems	I2 supportive policies on new energy systems		
J. Investments in energy research	J1 low investment or none	J2 high level of investment		
M. Cooperation between government, private investors, NGOs	M1 nonexistent or low	M2 existent or good	M3 excellent	
N. Added Value creation from the renewable energy sector	N1 nonexistent or very low	N2 existent or good		
O. Financial market in rural economy	O1 limited access to formal financial market	O2 access to informal financial market	O3 no access to formal or informal market	
P. Legal System	P1 law enforcement	P2 aggravated	P3 not effectively enforced (current)	
Q. Climate change	Q1 high impact	Q2 low impact		
R. Environmental effects on population	R1 high impact	R2 low impact		
S. Women's empowerment	S1 limited or no empowerment	S2 fully attained	S3 partial	
T. Community organization	T1 poor community organization	T2 limited to labor	T3 support includes economic contribution	

"How can we create a society, a culture, that will not deny our humanity but will also not change it into an empty abstraction? we are attempting to create a society which is not ruled by lies and betrayals, by avarice and violence and dissimulation. A society that does not make man an instrument of the state. A human society"

— Octavio Paz (1959)

7. Adaptation to local conditions

A singular shortcoming of sustainability models is the lack of local adaptation to respective regional conditions (Hartmuth et al., 2008). One of the main setbacks is the acceptance of the new system by the population, since the feeling of an imposed model makes it inadequate, hence, not entirely successful. The objective is a fine-tuning of the global goals of sustainability and the local circumstances, which means that the sustainability rules need to be tailored for the local context (see section 5.1).

Chapters 6 - 9 form Part 4 of this dissertation; the application of the method and results presentation (see chapter 0). A detailed overview is presented here. The following sections 7.1, 7.2 and 7.3 present the acculturation of the main ICoS rules, evaluated and contextualized under Mixteca conditions. In chapter 0, eighteen indicators / criteria describing the system were identified. Per the workflow presented in section 5.3 (see Figure 25), the ICoS goals and rules were evaluated through these criteria. Nevertheless, the ICoS rules needed to be adapted to the particular local conditions of Mixteca before the *Scenario-based sustainability assessment* could take place. Hence, the indicators proposed by ICoS are used as reference guide for the area, and their assessment was expected to provide information as to whether the region would become closer to or further from the ICoS sustainability goals. The result of the contextualization - the indicators and targets set up for the descriptors / criteria - are presented in section 7.4. Section 7.5 provides the contextualization of the ICoS instrumental rules as the framework conditions needed in order to reach the sustainability goals defined by ICoS (see Table 5 in section 5.1).

7.1 ICoS goal 1: Securing human existence

The concept of securing human existence can be a complex and even site-specific conceptualization, with interconnections between the different aims – rules - and the time dimension, in such a way that the satisfaction of basic needs such as (nutritious) food and (suitable) housing strongly influence a better quality of health; a healthier person can benefit more from education, which in turn could translate into skilled people whose employment opportunities could increase and lead to better income. Better education could also raise awareness of responsible use of water, electricity and natural resources, as well as concern about pollution and human influence on climate change. Therefore, a comprehensive strategy would evaluate the interconnections between these aims over time and their evolution, and implement a set of policies to ensure that conditions are given to make basic services, education and health services available to vulnerable populations so they can benefit from them.

The most pressing concern in Mixteca is related to the criteria of basic existence: basic needs are not covered. Environmental-related problems are visible only because of their consequences, with a failure to notice the direct influence of human beings in the origin of the problem. Of particular concern are issues related to water scarcity as well as water pollution. In order to end poverty, every member of the community, of all ages and groups, should have the right to health protection, access to basic needs, opportunities to secure their existence based on their own work through decent and fair jobs, and opportunities to use natural resources.

7.1.1 Rule 1.1: Protection of human health

In rural or vulnerable areas, as in the case of Mixteca, health benefits are neglected. Rural areas might suggest a notion of wellbeing and this can be true (less pollution, less noise, fewer factories), however, the reality for inhabitants of rural communities attempting to access equitable health services or a wellbeing status is far from optimal. There is a lack of understanding of rural needs, and the belief still prevails that rural areas immersed in the countryside can restore the effects of any pollution generated "regardless" of the amount (Secretaría de Medio Ambiente y Recursos Naturales, 2008). From the ecological point of view, human activities and the environment are connected. The air emissions from a nearby urban area will eventually reach the atmosphere in the surrounding rural regions (World Health Organization, 2006). The case of Mixteca is no different, the air- and water-pollution levels registered in the urban capital will eventually reach rivers and air if it has not already occurred. Sewage discharge pollutes subsurface waters and underwater reservoirs; it is also the main source of heavy metal contamination. Pesticides used in agriculture are of special concern. Some have been banned for a long time, yet they can still be found in soil and water (Dane and Perticará, 2013).

Moreover, due to the weak rule of law and poor law enforcement, small assembly factories and establishments move out of urban areas and are installed in nearby rural regions where air emissions, water pollution and noise levels are not controlled, usually regarded as insignificant. Often, the "employment" narrative adopted by these entities is used to bypass law enforcement, and local governments shelter and protect them. Fairly "relaxed policies" apply (Micheli, 2002).

High mortality from air pollution, i.e., solid suspended particles PM and O3, has been observed; around 30,000 people died in Mexico in 2016 due to air pollution caused by high levels of these air particles (Climate Transparency, 2020). Human health is affected by heart diseases, lung cancer and chronic respiratory diseases. To reduce the projected increase in deaths from air pollution, efficient methods of tracking and control need to be implemented before they become dangerous and threaten human health. Regions suffering from an increased human activity load have higher numbers of people with disabilities and chronic diseases, so it is no wonder this group of people is economically vulnerable. Human health protection is undervalued in Mixteca. Local and regional practices and initiatives should be linked by governments and NGOs so that appropriate care can be provided to the population in the sustainable protection of human health.

In the context of this work, the criterion *R. Environmental effects on population* is used to assess this rule (see Table 8 in Chapter 0).

7.1.2 Rule 1.2: Ensuring satisfaction of basic needs

The most basic need in Mixteca is survival. The area is poverty-ridden, and less than 4% of the population is not poor and not vulnerable (see section 3.5). The rest of the inhabitants struggle between moderate poverty or extreme poverty (around 266,500 residents). Consequently, the most relevant basic needs to guarantee survival are: food and drinking water (which is not guaranteed in the area), clothing, housing, healthcare, education; meaning electricity and sanitation are not the main priority. The quality of food tends to be low and non-nutritious; housing is usually inadequate, with poor materials and / or many people living under one roof (INEGI, 2020b).

According to the Food and Agriculture Organization of the United Nations (FAO), food security exists when "all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The state of food security in Mixteca is critical, at least a fifth of the population in the region do not meet the threshold. In addition, malnutrition is also present as a consequence. Lack of access to electricity is related to poverty (IEA, 2020b). The provision of energy and electricity to each household is one of the basic needs that play a role in the development of the country, and although provision in the area is high, the service is not stable and cannot be used for productive purposes, hence basic needs cannot be considered fully covered for all inhabitants of the area. Satisfying basic human needs while ensuring ecological sustainability are necessary preconditions for sustainable development that are currently not in place in Mixteca.

In the context of this work, the following criteria are used to assess this rule: *A. Emigration, C. Education* and *E. Basic services access* (see Table 8 in Chapter 0).

7.1.3 Rule 1.3: Autonomous subsistence based on income from own work

Nearly one-third of the population in Mixteca is economically active, nevertheless, about 85% of the working population earns less than the minimum wage (author's calculation based on data from (CONEVAL, 2018b)). Not only is their income meager, but their growth opportunities are also scant, and sometimes unsafe work conditions prevail. Consequently, a fair autonomous subsistence is not guaranteed, hence the strong remittance-dependence on emigrants abroad. There are no real opportunities to exert control over one's employment situation, and as a consequence, physical and mental wellness deteriorate, and self-confidence sinks.

The informal economy (mainly street vendors) in the area is an attempt to compensate through "formally unearned" income, usually performed by children and women; this activity is estimated to represent about 60% of the economy. Studies suggest that unemployed people as well as low-quality employment individuals have an equally strong link to poor general and mental health, highlighting the importance of job quality in addition to merely promoting employment for the unemployed (Burgard and Lin, 2013; Leach et al., 2010). Despite the emphasis that any job is not necessarily better for health than no job at all (Van Aerden et al., 2017), Mixteca's focus is on securing human existence. Having a secure income could at least guarantee survival.

While it is true in principle that the inhabitants in Mixteca are free to choose the employment opportunity or income source that best fits their interests, in practice, given the population's low (or nonexistent) capacity-building and education, inhabitants face restrictions in joining the labor market. Moreover, they are not fully developing their potential, as they are focused on survival through any opportunity and any means; consequently, they cannot choose among options nor are they prepared – educated - to choose. Demanding job satisfaction is meaningless compared to being in an unemployed situation. The sense of purpose, individual development and wellness are undermined and meaningless, and the focus is aligned to obtain an economic benefit to secure their and their family's existence. Therefore, emigration is a suitable alternative to search for an autonomous subsistence, where people might not develop an activity they would enjoy, but it compensates with better earnings.

In the context of this work, the following criteria are used to assess this rule: *D. Source of income, G. Job and earnings,* and *A. Emigration* (see Table 8 in Chapter 0).

7.1.4 Rule 1.4: Just distribution of access to natural resources

While the population in the area has access to a limited amount of resources, e.g., water, electricity, compared to inhabitants in urban areas, they are the foremost affected by a imbalance of supply, enduring a lack of resources to procure their living. Due to the restricted supply of resources, the amount of energy, water consumption and raw material usage in Mixteca becomes lower than in urban areas. There is an unequal distribution of chances to use and dispose of natural resources, but at the same time, the region is the foremost affected by climate change consequences such as drought and rainfall variation (Gobierno del Estado de Puebla, 2011). The inhabitants are also the last to receive support, health care or access to basic services whenever a natural disaster strikes (Redacción El Popular, 2021).

In the context of this work, the criterion *Q. Climate change* is used to assess this rule (see Table 8 in Chapter 0).

7.1.5 Rule 1.5: Reduction of extreme income or wealth inequalities

Mexico is the second most unequal country in Latin America, with the top 10% of the population capturing 57% of the average national income, and is among the countries with the highest inequality and lowest social mobility in the world (Chancel et al., 2021). Less than 3 % of those born in the lowest quintile will move up to the top quintile, and only 2 % from the top quintile will end up at the bottom (Delajara and Graña, 2017). While around 50% of the population lives beneath the poverty line, the four richest men hold wealth equivalent to 9 % of GDP (Esquivel, 2015). Inequality is not just determined by economic forces, it is shaped by politics and policies, e.g., taxes, minimum wage levels, investment in health care and education, which exert channels of power and control. Poor supervision of the rule of law has allowed common practices such as employment without contracts, where salaries are undervalued to avoid tax payments, and work to continue the unequal distribution of income in Mixteca. As a consequence, the population below the minimum wage in Mixteca is estimated to be about 85% (author's calculation per information from (CONEVAL, 2018a)).

Mixteca encounters the consequences of unequal wealth distribution: while the area endures poverty and a lack of opportunities to support their living, urban areas benefit from higher incomes and employment opportunities. Reducing inequality has clear economic as well as social benefits. It improves social mobility and cohesion, setting the path to societal fairness; broadening support for growth initiatives allowing the population to develop their potential. Policies that pursue growth but ignore inequality may ultimately be counterproductive, while policies that decrease inequality, for example, by boosting employment and education, have beneficial effects on the human capital (Doyle and Stiglitz, 2014) that societies like Mixteca increasingly need.

Social inequalities are more pernicious forms of inequality, particularly in the fields of education and occupation. Widely documented as inequality of opportunity, this is both the cause and consequence of inequality, it causes economic impairment and reduces development, as inhabitants are not able to fulfill nor develop their entire capacity (Easterly, 2007).

The lack of socioeconomic mobility in Mixteca is a reflection of the inequality of opportunity within the state and the country. Research shows (Delajara and Graña, 2017; Monroy-Gómez-Franco et al., 2018) that due to its geographic location, children in Mixteca will hardly improve their socio-economic situation compared to that of their parents, as fewer opportunities across generations will arise, sentencing them to remain in poverty and vulnerability. The fact that those born into the bottom of the economic pyramid are condemned to never reach their potential reinforces the correlation between inequality and slower (or lack of, as in the case of Mixteca) long-term economic growth (Corak, 2013).

The socio dimensions of inequality in Mixteca are correlated, which is the reason why focusing on one aspect at a time might not be useful to tackle inequality. For instance, health conditions are a cause and at the same time the consequence of income inequality. Education is a fundamental determinant of inequalities in income, occupation and opportunity. Mixteca is also affected by an increased social inequality associated with ethnicity, which also prevents social mobility. In Mixteca, the ratio of less income due to indigenous municipality vs non-indigenous is estimated to be 53.6% (author's calculation from data from (CONEVAL, 2018b)). The fact that inequality threatens poverty eradication, sustainable development and social cohesion is undeniable. Societies with high inequality tend to invest less in public goods, such as infrastructure, technology, and education, which contribute to long-term economic prosperity and growth (Streeten et al., 1981). This strategy that meeting basic needs (viewed as a short-term target) is more important than reducing inequality seems to extend the poverty cycle. When meeting basic needs becomes a long-term strategy, this approach could be problematic as it avoids the necessary investment in public goods; as a consequence, inequality does not decrease, thus restricting sustainability.

In the context of this work, the criterion *G. Job and earnings* is used to assess this rule (see Table 8 in Chapter 0).

7.2 ICoS goal 2: Maintaining society´s productive potential

Present generations in Mixteca have a obligation to their forthcoming descendants; to have an interaction with the environment in the present that will bring a favorable value in the future. For that purpose, the recognition and current responsible use of natural capital's contribution to economic wellbeing are pivotal. Therefore, while taking full note of the importance of human wellbeing in maintaining and expanding productive potential, it is necessary not to lose sight of the central importance of the needs of future generations, by framing the sustainable conception of the wellbeing of the future in a way that is at more or less similar to the current wellbeing in the area, according to the ICoS rules. However, since the present general productive potential in Mixteca is not favorable, the sustainable interpretation would be an improvement of conditions for future use of resources, which could lead to an improvement in economic potential, leading in turn to better living conditions in the future. For this purpose, the recognition of the intrinsic value of the natural capital is necessary, by using renewable and non-renewable resources in a sustainable way; not exceeding the threshold and assimilation capacity of the environment to regenerate. If society in Mixteca could become receptive to the responsible use of resources - renewable and non-renewable - then a realistic and useful understanding of human influence on the ecological systems in the area would bring special consideration for including human interactions and the use of the environment as a sink for waste.

Two rules of this goal number 2 were not addressed in this study, i.e., rule 2.2: *Sustainable use of non-renewable resources*, and rule 2.4: *Avoiding technical risks with potentially catastrophic impacts* (see Table 5 in section 5.1). These rules do not apply to this case which does not assess impacts on fossil fuels or any other non-renewable resource; in addition, critical resources and/or metals are not extracted in the region, nor is the population dedicated to its extraction in other areas. This case does not address a technological transition that represents potential catastrophic impacts in the area, i.e., in the event that a solar photovoltaic system would break down, there would not be devastating consequences to the environment or a threat to human life or health.

7.2.1 Rule 2.1: Sustainable use of renewable resources

Due to limited resources, people in Mixteca are used to leading a life based on minimum resources. It could be useful for other regions to adopt some of these limited resources practices to develop habits that can promote resource conservation. However, activities which are required for survival in Mixteca could also be triggers for natural resource depletion. The loss of flora and fauna severely affects the capacity of the ecosystem in Mixteca to regenerate, and thereby impacts the flow of natural resources for human wellbeing. Such losses may even cause shifts into undesirable states in the landscape, as has been the case from the extensive use of wood as biomass for cooking and heating, and the introduction of livestock breeding and farming which have contributed to the land erosion (Gobierno del Estado de Puebla, 2011), hence less natural capital. However, these are activities related to human survival. Even agriculture, an activity required for survival, can also be a driver of deforestation if it is not carried out properly (imbalance of nutrients due to poor cycling, for instance). Therefore, this is not only about ensuring the survival of human beings and protection of biodiversity, but – from the socio-ecological perspective – nature is vital for people when it is able to provide such nonmaterial needs as health, recreation, education, etc.

People in Mixteca perceive a self-regulatory capacity of the flora and fauna and land systems. They also acknowledge there are boundaries and that the threshold capacity may have been crossed. Nevertheless, they are still not aware of how much influence their actions can permeate into the deterioration of the ecosystem. Moreover, some interrelations within the wildlife chain might not be clear, e.g., the growth of foreign plant species to make faster profits could affect small mammals' habitats ,which are then killed when they come into contact with humans while looking for shelter or food (Chagoya Lizama, 2011).

The use of charcoal in Mixteca is a preferred energy source for cooking (INEGI, 2017). There is low awareness - or knowledge – of a link between air emissions, pollution, health problems, deforestation and desertification due to this practice. However, if the population cannot afford or get access to a sustainable means of cooking, it will be hard to change this practice, whatever their level of awareness. A cultural value is also added to this practice, as the taste of the food is related to the traditional way of cooking.

The Declaration on the Rights of Peasants and Other People Working in Rural Areas (United Nations, 2019) stipulates that “people working in rural areas have the right to have access to and to use sustainably the natural resources present in their communities that are required to enjoy adequate living conditions”, moreover, they “have the right to participate in the management of these resources”. As long as inhabitants in Mixteca do not consider their existence to be secure, sustainability is not considered a priority. In addition, people will not be able to cope with the challenge if they are not fully aware of the consequences of using renewable resources in an unsustainable way.

The promotion of investment in solar energy research and production is a good starting point to educate, and support sustainable use of renewable energy production, since its benefits can be “immediately” translated into tangible results, adding value to the activity and promoting development in the area.

In the context of this work, the following criteria are used to assess this rule: *J. Investments in energy research* and *N. Added value creation from the renewable energy sector* (Table 8 in Chapter 0).

7.2.2 Rule 2.3: Sustainable use of the environment as a sink for waste and emissions

The human use and abuse of natural resources demonstrate how the loss of diversity through depletion, deforestation and extinction of ecosystems have resulted in eroded resilience and increased vulnerability in a region. A disturbance event, such as a different land use practice - the introduction of non-native species - might have become the trigger that caused the ecosystem to shift from one ecosystem state to another (Hernández et al., 2011), and may be virtually irreversible, e.g., semi-desertification in Mixteca. The new ecosystem state may not generate the same level, or even the same type, of source and sink functions as before, and thereby cause social and economic disruption.

Mixteca has been used as the supplier of natural resources, e.g., soil and stone used for building materials, and exotic native flora and fauna, and consequently, a depletion of natural resources has been taking place. Conversely, since there is no suitable solid waste disposal in the region, people in rural Mixteca usually burn the waste in open-air fields whenever there is a lack of service collection from the municipality. Hence, waste disposal and pollution are not under control. Riverbanks are usually dumping places for solid waste, which has led to the pollution of rivers. Discharges from manufacturing facilities are also channeled to the rivers as a functioning wastewater plant onsite is not available. The population emigrates rather than looking for solutions to environmental pollution. There is not an understanding in the area of sustainable use of the environment, which is used as a sink for waste, contrary to the ICoS rule. As a consequence, there is a poor productive potential for the society in Mixteca. Not surprisingly, the effects of climate change are not only evident in the area or state but in the vast part of the country.

In the context of this work, the following criteria are used to assess this rule: *Q. Climate change* and *R. Environmental effects on population* (see Table 8 in Chapter 0).

7.2.3 Rule 2.5: Sustainable development of human-made, human and knowledge capital

Human and knowledge capital are currently mostly focused on maintaining the traditions, languages, and customs of indigenous groups in the area. The traditional way of exerting justice in the area, known as customary law ("usos y costumbres" in the Spanish language, see section 3.8), is deeply-rooted and is sometimes exerted harder than civil law in order to combat the poor rule of law and corruption at the national and state levels, which have penetrated the local government (Díaz-Cayeros et al., 2014). Above all, investment in human capital in Mixteca translates into cultivating the society´s potential, which will, in turn, create added value to the region, thus maintaining society´s productive potential.

The undoubted importance of the availability of knowledge and information and the promotion of education and research for social development and the functioning of a country has increased significantly in recent years. Nevertheless, in Mixteca, these opportunities seem still far from being available (Caballero, 2012). The most basic stable education and knowledge requisites that must be created in Mixteca have not been given proper attention up to now. In addition, further education and training opportunities for future and continuous learning should be available. Education in the languages of the native groups should include all social groups and self-determination rights. If not, the risk of not attaining social development is high. In addition to the usual socio-economic focus, the institutional and organizational framework must also be considered so that these opportunities are available for current and future generations in Mixteca.

In the context of this work, the following criteria are used to assess this rule: *A. Emigration, C. Education, I. Governmental policies for integrated energy system, P. Legal system, and J. Investments in energy research* (see Table 8 in Chapter 0).

7.3 ICoS goal 3: Preserving society´s options for development and action

According to the Brundtland Report, people are entitled to have aspirations for more than just covering their basic needs: "Sustainable development requires meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life" (Brundtland and Khalid, 1987). Nonmaterial needs are important not only because they are valued in their own right, but also because they are important conditions for meeting present and future wellbeing. For Mixteca these would include the consideration of needs for the native group's self-determination, along with proper conservation of their millennial heritage, support for dissemination of their native languages and cultural identity; the inclusive participation of every member of the communities in the decision-making processes that affect them; equal access for women, indigenous communities and vulnerable groups to education and work opportunities to foster a sense of belonging and purpose in life and work; self-reliance on community action in the preservation of valuable social resources on resilience building. Community social strengths in Mixteca are valuable to preserve the social structure in community development, including the ability to accept changes and adapt to future conditions to exert a sustainable society.

7.3.1 Rule 3.1: Equal access for all people to information, education, occupation

There is the surprising finding that education makes people happier despite making them more aware of potential problems (Lutz, 2015). Moreover, an inclusive education reduces vulnerability to natural disasters and helps people adapt to climate change. Vulnerable groups in Mixteca, such as children, indigenous people and women, do not receive the same opportunities in education, information or occupation (Alvarez-Castillo et al., 2009; Delajara and Graña, 2017). To have an equal opportunity and a first step into sustainability, recognition as an individual with rights is needed.

The first intervention to tackle inequality is to provide the necessary opportunities to get people educated. Preparation and dissemination of knowledge are important, however, if people do not have the means to make use of that knowledge, it will not be useful. Rather than being a social equalizer, education in Mexico works as a mechanism of stratification, as it effectively contributes to increasing inequality when the children of those who have been wealthy and powerful for decades have become richer and more privileged (Amis et al., 2020). Equality of satisfactory educational opportunities does not exist in the status quo in Mexico and this is aggravated in rural areas (INEGI, 2016; Patiño Tovar, 2003) as Mixteca.

Reducing inequalities between children requires integrated and very early interventions in ensuring a safe environment, in cognitive development, in early years of school learning, proper nutrition and health care for young children. These opportunities should be provided to children at a very young age, otherwise benefits will be much less effective. Consequences for society in Mixteca are visible: the underdevelopment of valuable human capital whose pattern has repeated from one generation to the next. Low-income families cannot provide opportunities for development to their children, who will then grow up to be low-income parents themselves, impeding intergenerational income mobility (Esquivel, 2015). Children in Mixteca have multiple means to access an informal job opportunity, as they assist their parents selling in markets, or on construction sites, and harvesting, while they miss the opportunity to get a proper education.

Besides discrimination towards the poor, racial stereotyping is pervasive in the country, as the association between income and skin color is an observed fact in Mexico (Solís et al., 2019). The respective opportunities between the poor indigenous person and someone belonging to the highest quintile (of the socioeconomic stratification ladder), differ from the outset. It conveys the impression they live in a country where different socioeconomic groups have different realities. It also exhibits signs that they are governed by different laws, because being wealthy grants power and options to influence political strategies, policies or business investments (private and public), and exert influence over regulatory agencies or politicians via fund donation, not to mention corruption and bribery. The common motto: “if you have the money you can buy justice” (Esquivel, 2015) can be used to explain the inequality of opportunities in Mixteca: if you have the money you can get education, services, access to better jobs and income opportunities. The frequent combination of economic, social and political capital provides the wealthy sector with bargaining power, the voice and assets to influence policy outcomes - should they wish to do so.

The prospects of opportunities for children in Mixteca can also be influenced through family culture, and other qualities that shape skills, aptitudes, beliefs and behaviors are a value-judgment that different communities or societies may make differently. Unequal access to opportunities for the population in Mixteca is also a result of a prolonged social mobility stagnation in the area, where chances to improve are minimal, i.e., non-existent, which is reason why emigration is a likely route (Patiño Tovar, 2003) in the quest for access to any opportunity to improve wellbeing. Although slightly more than half of Mixteca’s population consists of women (INEGI, 2020a), they do not have equal opportunities for growth and development. They are still behind in education, health, income opportunities generation, asset ownership, and even major household decision-making processes (Pedrero Nieto, 2002). Women are denied their rightful place in society, and they are compelled to stay at home, care for children and the elderly, manage households (food supply, collect water, animal farming, wood collection). In some extreme cases that persist, young women – girls - in the poorest families are exchanged or sold for marriage as part of the customary law ("usos y costumbres" see section 9.2.3) in order to leverage an economic burden for the family and future economic benefit to the rest of the family members. Young girls' marriage affects women's education, threatening their future empowerment (Mim, 2017). Lack of opportunities to access education translates into limited development of skills and autonomy and limited opportunities in the job market. Women's participation is fundamental to the economic growth and development of the area, so equal opportunities to develop as a human being should be granted.

In the context of this work, the following criteria are used to assess this rule: *A. Emigration, C. Education, and S. Women's empowerment* (see Table 8 in Chapter 0).

7.3.2 Rule 3.2: Participation in societal decision-making processes

Participation in societal decision-making processes should be relevant and practical to improve collaborative communication, rather than just a political discourse platform. It is important to note that situations which are not addressed are not likely to be resolved and thus the challenge will remain. Full participation is not always guaranteed in Mixteca. Social engagement takes time to develop, and a range of factors could prevent those in the poorest sector from taking part if they consider themselves marginal or alienated from the power of decision-making: disorganization, ignorance on "how to participate" or "if a member should/can participate", when rules seem unclear, and a lack of education (Lucas and Alvarez Castillo, 2013; Pedrero Nieto, 2002).

Participation and community involvement have been in the political discourse for some decades in Mixteca. People are aware they form part of a rhetoric through which the local government intends - and so far has succeeded - to obtain economic resources that will not reach or benefit the community (Esquivel, 2015). In this case, community participation turns into the manipulation of true needs and intentions, as shown in the first level of the "ladder of citizen participation" proposed by Arnstein. For participation to be effective, power has to be redistributed for participation; without power, it is a hollow, and fruitless process for the poor and the weak. In reality, under such a scenario, not everyone will benefit, other than the elite (Arnstein, 1969).

Social participation can also be affected by challenging situations in Mixteca, such as violence – including domestic abuse - organized crime (still not present in the area but a potential threat), corruption, insecurity, political, social, and cultural inequities, a low level of education, and health.

The active participation of inhabitants in Mixteca and their engagement in community energy proposals and projects could trigger a smooth energy transition, as well as community self-determination and local government development initiatives. Their participation would not be limited to the role of consumers but rather to a producer role or "prosumer". An evolved degree of participation is desired for a sustainable future.

Community organization is ruled by a board elected by the population, nevertheless, not everybody is able to take part, depending on the community. Indigenous groups are strong and rule according to their expectations and experience (customary laws "usos y costumbres" see section 3.8) where civil rights are often not recognized. Some women are excluded: young girls are sold, women are subject to violence and forced to work in the household or fields - they have to look for a way to survive and are neglected the opportunity to participate in decision-making processes.

In the context of this work, the following criteria are used to assess this rule: *F. Population acceptance of renewable energy plans and participation, M. Cooperation between government, private investors, NGOs,* and *T. Community organization* (see Table 8 in Chapter 0).

7.3.3 Rule 3.3: Conservation of cultural heritage and cultural diversity

In Mixteca, indigenous groups accumulate several disadvantages across different dimensions: they have lower education, they are concentrated in scattered areas lacking health and basic services, with lower development of their communities, unfair availability of employment or income-generating activities, and access to poor infrastructures. These factors hinder their economic performance. The cultural heritage of their native language becomes a barrier to access quality education since the language of instruction is mostly enforced in Spanish. Speaking an indigenous language becomes more than a barrier it is a motivation of shame or discomfort when someone is outside their community, among Spanish-only speakers. It has become a signal of degradation or humiliation due to the association with the vulnerable conditions where they usually live (Pastrana Peláez). They also face unfair employment circumstances and lower payment due to their language and direct ethnicity. as there is a negative stereotype that someone who cannot understand Spanish is ignorant, and therefore lacks culture. This is especially dehumanizing when the native community member is a proud living cultural holder.

Indigenous groups are more likely to work in low-paid sectors with limited progression opportunities (usually embroidering traditional textiles, tanning leather, pottery, minor agricultural practices for self-subsistence whose excess is sold in markets). These activities usually show ethnic distinctive design and imprinting, seen as traditional from their culture. Since these articles are sold as ornaments, people tend to lack appreciation for them, and do not value the time, effort and cultural value invested in these goods. People usually bargain to buy undervalued products whose utility is not a basic need, rather than experiencing an expression of the cultural identity of a specific group.

In the context of this work, the criterion *B. Ethnic identification* is used to assess this rule (see Table 8 in Chapter 0).

7.3.4 Rule 3.4: Conservation of the cultural function of nature

Ancient Mixteca civilization has its origins in a symbiotic relationship with nature which extends up to now. The physical human body and spirit are considered as interconnected entities with nature, whose balance must be taken care of. An imbalance in any of these components would translate into chaos. Nature is considered a living and sacred entity, a fundamental pillar of a religious ideology given the provisioned capacity of shelter, clothing and nourishment. Respect and appreciation for nature are at the center of Mixteca culture. Historically, a harmonious and reciprocal relationship was sought. This could only be achieved through a symbolic exchange, whose purposes included: to compensate the imbalances generated by humankind in the natural system; to regulate the use of natural resources; to request and thus guarantee the satisfaction of the communities' basic needs; and to show appreciation to restore mind-soul-body stability. Flora, fauna, the sun, water and earth minerals are thought to hold healing properties. Traditional remedies and medicines are based on these; the knowledge to pass on from one generation to another is a privilege and a gift granted by the god of nature (Hernández Rodríguez et al., 2009; Lucas et al., 2013).

From Mixteca's perspective - the indigenous descendants of the inherited Mixteca culture - the moon, the sun, the rain, are living entities with the same attributes that human beings possess; that is, they have will change their moods and even age. They also possess the power to generate life or produce pain and death. The day someone is born does not only mean becoming part of a human community, it also grants access to immersion in an intrinsic relationship with the landscape. This idea reinforces the sacredness of the place through time, and therefore of a sacred landscape. There are communal statutes for lands that are used for ritual ceremonies or sacred places, those that have been used by the community for traditional ceremonies, and those that are considered sacred by the ancestors. These types of land are protected areas by the communities and reinforced through the recognized customary law ("usos y costumbres" see section 3.8)

In the context of this work, the criterion *B. Ethnic identification* is used to assess this rule (see Table 8 in Chapter 0).

7.3.5 Rule 3.5: Conservation of social resources (tolerance, solidarity...)

One way to represent social cohesion in Mixteca society is through the benefits that remittances bring to the community. First, it is the commitment from the emigrant to send financial resources to the community (Muñoz Jumilla, 2006). Many times, these funds are assigned to common tasks within the town (a building improvement, basic service infrastructure), or contribute to common festivities which are a strong bond to social traditions in the area. Nevertheless, there is an ambiguity / contradiction here: sustainable development should aim to decrease the amount of such remittances and promote independence and job creation. At the same time, remittances bring prosperity to the area and could also contribute to job creation, and most importantly, to social resources by strengthening the bond among the inhabitants of the region.

Social resources are a potential guiding principle of society in Mixteca, given that material sources are scarce. Solidarity motivates collective action, new projects, entrepreneurship, and risk-taking. It builds a sense of belonging or identity. Solidarity in Mixteca is usually channeled through work towards a common goal, in the understanding that it usually conveys assisting in building a neighbor's house, the local church, a public market, a community center, offices for the local government, or a bridge. What unites people is not necessarily their sense of identity, kindness or any positive similarity, but they try to overcome a negative emotional reaction to something that strikes them as unjust, such as a natural disaster or the effects of poverty.

In some other instances, the status of poverty prompts a reactive effect, resulting in a moral obligation to a shared commitment to a specific cause. Sometimes, a reaction to experiences of perceived suffering or injustice builds these bonds of tolerance, trust, reciprocity, participation and collective action. Resilience is an integrating concept that can be used as a bridge between emergencies (droughts, floods, scarcity) and development. To be able to survive, communities in Mixteca have developed a high resilience level. Nevertheless, beyond this adaptive capacity, communities need to experience less marginalization and more wellbeing. Inhabitants also develop a disposition to provide in any way possible, mostly with their work, but when it is possible, with financial resources, encouraging networks of assistance and cooperation to cope with vulnerability (Mercado, 2015). This is often seen during religious festivities, giving a stance for uplifting the spirit.

These social resources could be the trigger point for participation and action. They also influence the course of the region, enhancing the collective capacity of the citizens, although this has not reached a maturity point regarding institutions. Additional work is needed to strengthen the capacity-building of these institutions so that social resources can be used to achieve society's options for development and action in both general contexts and daily activities, and not only on specific situations during negative experiences (disasters, emergencies).

In the context of this work, the criterion *D. Source of income* is used to assess this rule (see Table 8 in Chapter 0).

7.4 Setting up indicators and targets

In chapter 0 the characterization of the Mixteca system was presented, where eighteen descriptors were selected as drivers of future scenarios for the solar PV transition. In this chapter (0), the contextualization of the main goals of ICoS has taken place, so that the eighteen identified descriptors could be understood as base criteria for the *Scenario-based sustainability assessment*. Primarily, the CIB analysis is based on future long-term trends; since actions are needed to adjust the current situation to allow a future significant impact, a sufficient timeframe is required for the system to appropriately adopt suggested changes. A suitable indicator and a target that reflect future performance for each descriptor / criterion need to be selected in order to evaluate the performance of the descriptor / criterion in the future. A relevant target with a sustainable perspective is presented along this section to each descriptor / criterion and evaluation references are selected (see Figure 25 in chapter 5).

The targets assigned are the references to which the indicators are compared. These should assist decision-makers in the future performance of a criterion. Targets were selected through literature review and stakeholder involvement and agreement. The selection process involved national standards or regulations (e.g., air emissions), national statistical performance (e.g., emigration rate, renewable energy share), international tracking statistics (e.g., corruption perception index). Most of the targets are subjective and desirable indicators, and some targets (e.g., number of local community projects, number of local energy projects) were proposed based on the UN central premise of the 2030 SDGs to eradicate poverty, end exclusion and reduce inequalities: "Leaving no one behind" (United Nations Development Programme, 2018). For those indicators where no targets were available or discussed, either in local, national or international standards, conclusion by analogy and the SDGs motto "Leaving no one behind" was chosen to define targets (e.g., loans to productive activities in Mixteca). The following paragraphs present the indicators and targets selected for each of the eighteen descriptors / criteria within Mixteca's identified solar PV transition system (see Table 8 in Chapter 0).

A. Emigration. The designated indicator to monitor future performance for this criterion is the emigration rate, since it measures the flow of inhabitants leaving or returning to their place of origin. It is a suitable indicator since the population flow has been monitored for many decades, hence, statistics methods and values are trustworthy (Consejo Nacional de Población and Fundación BBVA, 2021); it is also related to the remittance flows, therefore, economic dependence to compensate missing income could boost the wellbeing of the rural population. A desired target for future development in the area would be a significant reduction in emigration flows, since a region depleted of inhabitants has no prospects for future prosperity or growth. A discussion point might allow consideration whether fewer emigrants would also sink the remittance flow, and families' incomes would be affected. An alternative consideration would be that the emigrants who left in the past would return with better skills, and possibly also with financial capital to start a small business in Mixteca to compensate for the missing remittances.

B. Ethnic identification. A language is an important cultural element related to a group of people. It is much more than just a system of communication between its members, as it also reflects the collective conception of the group within a region. A native language in Mixteca also reflects a specific perspective that might involve a group of people's interactions with nature and with each other; they reflect in their language the way they conceive human-earth relations (natural resources relationship) and social relations. The words they use when they express their thoughts, feelings and desires reflect their native logic and philosophy (Valtierra Arango, 2012). Consequently, their native language is part of the group's identity. Mixteca's identity is an intangible part of its cultural heritage that should be preserved as an important social cohesion factor, currently threatened by vulnerability. To this end, the suggested indicator for ethnic identification is the number of indigenous language speakers in the region. The proposed target is to increase considerably the number of inhabitants speaking an indigenous language, since these speakers are key to ensuring the continuation and transmission of culture, customs and history as part of the heritage and identity of Mixteca's native groups.

C. Education. The indicator chosen to measure progress in education is years of schooling, since the better prepared a person is, the better informed they will be to make decisions impacting the community. The complete fulfillment of basic and secondary years of schooling can help to foster the development of the required competencies - including the sustainability component - to be empowered to act in future complex situations. In order to improve living conditions in Mixteca, it is desirable that an increase in years of schooling takes place. It should be pointed out that the aim is to improve not only the number of years of schooling, but also its quality, by promoting the development of interpersonal competences, including anticipatory thinking, empathy and perspective, a sense of interdisciplinary work, fair and ecological action, innovation and tolerance (Wiek et al., 2011). Compulsory primary and secondary school attendance should be attained. In addition, it is highly desired to count on a structured occupational education with soft skills, so that strategic thinking and interpersonal abilities can be incorporated into daily problem-solving situations that would secure the society's existence in the area, along with satisfaction of basic need.

D. Source of income. The indicator selected for this criterion is the value of remittances. Remittances are an important financial support for many families in Mixteca, as well as a means of social and family cohesion between the emigrant and their family in the rural region (Fox, 2006). Remittance inflows have consistently increased in Mixteca over the years (see chapter 0), creating high financial dependency which inhibits employment and capacity-building. An ambiguity that needs to be addressed here is that sustainable development should aim to decrease the value of remittances and promote independence and job creation. At the same time, remittances bring financial resources and prosperity to the area and could also contribute to (self)employment. Consequently, the proposed target is a substantial decrease in remittances, along with an increase in job creation and investment opportunities from the government, third parties or cooperatives within the rural area.

E. Basic services access (water, electricity, drainage). Access to clean water and sanitation as well as access to affordable and clean energy are UN SDGs (numbers 6 and 7 respectively) (United Nations, 2022), for a sustainable future, since they underpin poverty reduction, economic growth and environmental sustainability. An appropriate indicator for this criterion is the percentage of population coverage in basic services, whose aim should be to ensure that no-one is left behind in the path to sustainable development. This goal also provides the opportunity to recognize the inhabitants´ basic right to these resources, contributing to poverty alleviation. Hence an inclusive and desired target would be to have a full coverage of basic services in Mixteca.

F. Population acceptance of renewable energy plans and participation. The extent to which a solar PV system could be introduced and implemented in Mixteca largely depends on the inhabitants and local communities' acceptance. It has been documented how acceptability is influenced by people's confidence and involvement in a project when it starts, or even while it is being planned, so that different opinions and constraints can lead to a positive influence on a collective decision (Devine-Wright, 2008). A suggested indicator to measure the progress of this criterion is the number of solar PV projects planned to be implemented or in process of implementation in a community whose proposed target is one per municipality.

G. Job and earnings. Decent jobs and fair wages are part of the UN SDG 8 (United Nations, 2022) whose aim is to increase income-generating employment opportunities as a tool to eradicate poverty. The selected indicator to track the progress of the criterion 'job and earnings' is the population rate earning below minimum wage, which in an ideal future should tend to disappear in order to guarantee a fair means of subsistence for the population and meet the sustainability goals. Nearly 85% of the economically active population in Mixteca earns less than the minimum wage (author's calculation per information from (INEGI, 2021)); this explains the degree of poverty and vulnerability prevailing in the area. A slight decrease cannot be considered sustainable, hence the need to address the present situation.

H. Governance uncertainties. The population's trust in the government is a common indicator of a public administration's performance and a measure of how well it is working (OECD, 2021). It reflects on policy stability, a government's responsiveness to change, and relies on long-term visions and on enforcing regulations. Hence, the indicator for this criterion is the approval level of governance by the population, whose target aims at a significant satisfaction of the population. Governance should provide the sustainable transformation of the society at all levels, promote inclusion, achieve climate change commitments, build effective institutions to access justice, and care for a productive society.

I. Governmental policies for an integrated energy system. An indicator that could provide solid accountability of governmental policies in the energy sector relates to the share of renewable energy (OECD, 2021) produced through a specific source. For this case study, it is proposed to use the share of solar PV energy produced in Mixteca, whose target is in the first instance to generate a significant amount of power that allows the population to use it for productive activities. This would help to strengthen the confidence of all involved stakeholders in the generation process and support further investments, at the same time, governmental policies are useful to plan for clean and affordable energy, increase the security of supply, efficiency and reduce costs.

J. Investments in energy research. Public investment has the capability to enhance productivity and promote growth as well as foster societal wellbeing, and such is the case for investment in solar energy research. The gross domestic expenditure on research and development in energy shows society's interest in and commitment to developing solutions for a greener economy with compatible infrastructure to sustain future needs. Renewable energy is the cheapest source of energy generation with the potential to alleviate climate change impacts. The government should be the first promoter to stir the change, hence a percentage of the GDP addressed to investment in energy research is a positive sign of this commitment. Since Mixteca is rich in high solar radiation, its future benefits and indicator can be triggered by investing a percentage of the Federal and State government GDP (OECD, 2021) in solar energy research in the region. Future benefits besides electricity provision in Mixteca are diverse, and include economic growth, poverty alleviation, decreased impacts on climate change, job creation, and thus a future productive society. The target for the indicator is a significant investment, and future increase to such an extent that supply could notably meet a share of the demand and avoid the use of fossil fuels.

M. Cooperation between government, private investors, NGOs. The interplay between government, private investors and NGOs provides more robust thinking and strategic foresight that can help tailor projects to particular circumstances and plan adequately to promote sustainable development (OECD, 2021). The proposed indicator is the loans destined for productive activities in Mixteca, one of the uses of which would be loans for investment in solar PV systems in different degrees: households or collective use. This involves cooperation between the three entities; the financial policies and framework are provided by the government, private investors would support with banking institutions and agreement on just and fair interest rates, and NGOs would support easing barriers and assisting the local population in the area. A desired target is that the loans should substantially increase bringing adequate support to the region.

N. Added Value creation from the renewable energy sector. The traditional indicator to measure added value creation is the contribution to the GDP of a country (Bulavskaya and Reynès, 2018), hence, to monitor the added value generated from solar PV energy in Mixteca, the GDP contribution of the area is proposed as the indicator. A desirable target is an increase of this added value, whose effects should involve job creation, increased capacity-building and project development and consequently increased wellbeing in Mixteca. Renewable energy employment creates skilled jobs that enhance performance, and provides opportunities to increase living standards. It also creates an opportunity to fill the gap for the growing numbers of unemployed youth who could avoid emigration from the rural region.

O. Financial market in rural economy. Adequate interest rates for loans for productive activities could achieve high financial inclusion for the vulnerable communities in Mixteca and make them less dependent on governmental welfare expenditure programs. Therefore, interest rates of loans are suggested as an indicator for tracking progress on adequate discounting for the financial market in rural Mixteca. The target is to have access to fair and just interest rates, preferably through Development bank credits rather than to commercial banks. Currently, only

9% of the population in Mixteca has access to credit loans at an interest rate of between 60 - 78% (ProDesarrollo Finanzas y Microempresa, 2019), hence the need to target fair and just interest rates.

P. Legal system. A strong legal system should be transparent, have integrity and be accountable at all levels and across all sectors of society. Corruption threatens the government, politicians, entrepreneurs and the daily life of society, and consequently, the corruption degree is a useful indicator (Transparency International, 2022) to measure progress for this criterion, whose target is to substantially decrease corruption in the area so that in a long-term future a zero-tolerance policy could be reached.

Q. Climate change. An increase in renewable energy share would help ameliorate the impacts of climate change and support the fight against it. In Mixteca, solar energy production would raise awareness of the positive ecological impact of avoiding using polluting energy generation sources. Hence, the share of renewable energy production is proposed as a useful indicator to monitor progress. The suggested target is to reach the official committed target of renewable energy share production of 50% by the 2050 (SENER, 2016-2020). Even though it is an ambitious target for Mixteca whose current solar energy production is zero, given the high radiation indexes and proposed solar PV transition, adopting this target should be aimed as a contributing entity.

R. Environmental effects on population. Exposure to particulate matter (PM) and ozone (O_3) emissions pose a threat to human health and increases death rates due to directly related chronic illnesses (World Health Organization, 2006). Since human lives are at risk when the level of pollution is not controlled or monitored, as is the case in Mixteca, the population will be vulnerable to environmental impacts if appropriate measures are not pursued. The indicators proposed to monitor the environmental effects on the population are the air emissions of PM with diameters 10 micrometers and smaller (PM_{10}), PM with diameters 2.5 micrometers and smaller ($PM_{2.5}$), and O_3. Therefore, it is suggested that emissions levels should not exceed the national targets set by the government (Secretaría de Salud, 2014a, 2014b), see Table 9 for details of the relevant indicator and its target.

S. Women's empowerment. A gender gap has been documented in most areas where women perform (schooling, work positions, leader positions, wages) and cannot be denied (World Economic Forum, 2020b). Mixteca is no exception, hence the proposed indicator is the women's employment ratio, i.e., the percentage of paid jobs held by women, with a target to substantially increase. Women already form part of the economic activities in the region, but their efforts are not recognized, as many take part-time or informal jobs which are not officially recorded to contribute to society's productive organization.

T. Community organization. Community projects could be a catalyst for deeper community integration, and might trigger social change and acceptance. Consequently, it is important to maintain social programs to bond communities in Mixteca. Related to, but also independent from the renewable local energy projects proposal, the community organization indicator proposes to maintain constant projects running independently from the solar energy projects, with the proposed initial target to keep a consistent rate of one community project per municipality to maintain the bond and good social resources in practice, which will support social cohesion and solidarity.

Table 9 provides a summary of the above indicators and targets selected for the eighteen descriptors / criteria for Mixteca solar PV transition assessment.

Table 9. Chosen indicators and targets for Mixteca's 18 descriptors / criteria.

Descriptor / Criterion	Indicator	Target
A. Emigration	Emigration rate	Substantial reduction
B. Ethnic identification	Indigenous language speakers	Considerably increase
C. Education	Years of schooling	Basic and secondary school completion, plus occupational education with soft skills
D. Source of income	Value of remittances	Remittances should decrease and capacity-building, jobs, investments should increase
E. Basic services access (water, electricity, drainage)	Population coverage of basic services	Complete coverage
F. Population acceptance of renewable energy plans and participation	Number of local solar energy projects	At least one per municipality
G. Job and earnings	Population rate below minimum wage	Considerably decrease tending to disappear
H. Governance uncertainties	Approval level of governance by the population	High satisfaction of the population
I. Governmental policies for integrated energy system	Amount of energy supplied from solar sources	Substantially increase
J. Investments in energy research	Expenditure on renewable energy research by the Government	Substantially increase
M. Cooperation between government, private investors, NGOs	Loans to productive activities in Mixteca	Substantially increase
N. Added Value creation from the renewable energy sector	GDP from solar energy	Significant generation
O. Financial market in rural economy	Interest rate of loans	Considerably decrease
P. Legal System	Corruption degree	Substantially decrease
Q. Climate change	Renewable energy share	50% renewable energy share by 2050
R. Environmental effects on population	$PM_{2.5}$	MxNOM annual: 12 µg/m^3
	PM_{10}	MxNOM 24h: 75 µg/m^3
	O_3	MxNOM: 0.070 ppm 8h/day
S. Women’s empowerment	Women’s employment rate	Substantially increase
T. Community organization	Number of community projects	At least one per municipality

7.5 Contextualizing the ICoS instrumental rules

Sections 7.1, 7.2 and 7.3 described the context conditions of each of the three main goals derived from the ICoS. Nevertheless, certain process rules are required for these three aims to be fulfilled so the development path in the solar transition in Mixteca can be assessed as sustainable. The fulfillment of the goals relies on implementing the institutional, political and economic framework conditions that put sustainable development into practice. These premises are the means through which a sustainable status in Mixteca can be reached (see section 5.1.5). The ecological costs incurred due to the depletion of natural resources either by abuse or by trade, as well as the loss of the site's cultural value are some of the socio-ecological costs worth internalizing in the region (rule 1, see 7.5.1). Incipient microfinance programs and self-financing groups are attempts to provide financial alternatives to adequate discounting in the region to guarantee intragenerational justice (rule 2, see 7.5.2). Lack of opportunities for investment, human capital building, and integration into the national market are some limitations for Mixteca's economic development (rule 3, see 7.5.3). The social interaction within the ecological system in Mixteca and its resonance capacity prompts a reflection regarding environmental disturbances in the future (see 7.5.4). Mixteca's ability for reflexivity is discussed among the diverse and at times detached actors in the various spheres: politics, economy, society (rule 7, see 7.5.5). Traditional and civil governance in the area has shaped the steering ability in Mixteca (see 7.5.6). A self-organization system in the area (also known as customary law) has promoted social cohesion within society (see 7.5.7). The way the balance of power in the area is understood and applied through economic power between societal actors is discussed in 7.5.8. Two framework conditions from the ICoS instrumental rules have not been applied to the Mixteca context (see Table 6 in section 5.1.5): the *limitation of public debt* (rule 3), and the *promotion of international cooperation* (rule 5), as they do not apply to this case of a poverty-ridden region lacking economic resources and with no commercial contact outside of the country.

7.5.1 Rule 1: Internalization of ecological and social costs

The main reason for the internalization of environmental and social costs is to make society aware of its intangible resources and the consequences of producing goods without appropriately linking impacts other than the economic cost of the supplies. By appropriately assigning an economic cost to those external factors, the impacts could be counted and the damage could be made visible. The challenge of quantification of these costs and how to make them visible arises, as well as the measures for internalization - pollution taxes, strict and effective laws. Other scarce goods needing internalization are time and alternative possible uses of the landscape, environment, nature and resources (Hueting and Leipert, 1990). The working conditions under which the scarce goods are acquired / produced should also be included. In Mixteca, children assisting their parents have to sacrifice their school time or their right to play in order to assist their parents in income-generation activities. The impact of these current actions is only valued economically in the present (more income in the families), but missing the opportunity to attend school at early ages will impact the future of those children, who will become adults with weak expectations of a decent and well-paid job.

It has long been recognized that traditional measures of cost value reflect only the physical value of the goods, which is inadequate to integrate the sustainability component. Potential pricing adjustments should reflect resource depletion, so in Mixteca the degradation of land, water, air and biodiversity should be included. The loss of ancient historical and cultural assets, as well as the loss of native language speakers, should also be recognized. This intrinsic value is not accounted for. The sale of ancient cultural assets to tourists or foreigners as souvenirs; the handling - mostly illegal - of flora and fauna (Secretaría de Medio Ambiente y Recursos Naturales, 2010) based on ornamental or assumed medical properties, ammonite fossil stones found in Mixteca, as well as marble and granite used for decoration, are perceived as a way of generating immediate economic benefits rather than depletion of the cultural ecosystem. Further, the expropriation of invaluable cultural capital as ornaments for decoration sold to smugglers who will re-sell to foreign tourists. There is a need for transformation of the social system to encourage the appropriation of cultural capital and recognition of the legacy from pre-Columbian cultures whose customs, languages and systems have survived and shape current communities' identities. Strategies should be designed to include the cultural value and legacy within the value of goods and services provided.

One challenge in dealing with ecological costs incurred in the generation of basic services is that these costs are considered irrelevant when the population lacks services. The consideration to generate basic services through renewable sources is a "nice to have" condition, but if it turns out to be more expensive for the end-user, then who will be willing to pay for it despite it being "environmentally friendly"? Education and awareness are needed to disseminate the ecological cost, impacts and future consequences of such decisions. The current mindset is that people are not willing to pay for services such as electricity when in the present time (or eventually in the past) they can get it for "free". This wider topic could be addressed by the provision of basic services through renewable sources, linking the effects of climate change and its consequences into daily life. The high poverty levels in the area are a significant impediment to acquire products manufactured under the social and ecological costs associated: people simply cannot afford them.

In the context of this work, the following criteria are used to assess this rule: *E. Basic services access, N. Added value creation from the renewable energy sector, and Q. Climate change* (see Table 8 in Chapter 0).

7.5.2 Rule 2: Adequate discounting

Long-term decisions taken with a certain degree of risk and cost should not jeopardize or indebt future generations if they are to be considered sustainable. In the case of a possible negative impact in the future, there will be no possibility of remedial action, especially when the effects are related to the health and life of coming generations. In Mixteca, the valuation of money through the interest rate plays a role in long-term commitments. Future generations could be affected - highly likely negatively -. Impacts could threaten the life or health of future generations. Hence an appropriate interest rate is of decisive importance. It reflects the valuation of the present and the future, the weighting of the interests of present and future generations. Nevertheless, a balance should be found, since underinvestment should also be prevented from causing disadvantage to future generations, as currently happens in Mixteca. A lack of investment in productive activities or adequate infrastructure in past generations has caused the current lack of perspective on the status quo in Mixteca.

Access to adequate financial services enables development, and a suitable and well-structured scheme is a precondition for advancement. Community microfinance programs, financial - savings - cooperatives, credit unions and self-financing local groups will help in the development of financing rural regions such as Mixteca. Microfinance enables the social and economic transformation of the region, providing capital resources to those living under poor conditions outside of the formal financing sector due to their low or no-income status. Research suggests that microfinance not only reduces the incidence of poverty, but also its depth and severity (Imai et al., 2012). The research findings support the assertion that microfinance is an effective tool for reducing poverty in most low-income countries by enabling vulnerable people to engage in self-employment and income-generating activities, which can help them to become less dependent on remittances and gain financial independence.

In Mixteca, self-financing family and neighborhood groups have enabled the members to be self-reliant, and develop entrepreneurship capacity to engage in economic activities to increase income-generating opportunities. Women have been a targeted group whose household income has enhanced and thus they have avoided money-lenders' high interest rates. They have also benefited in gaining empowerment to contribute to decision-making in the community. This also represents a solidarity activity that has supported poor and vulnerable groups who have been kept outside of the formal financial banking system. Native community members in Mixteca face significant challenges, including the lack of financial services, due to poor communication skills - language, financial terms, unfamiliarity with regulations - and discriminatory practices - lack of respect and low attention. Informal employment is another factor that inhibits vulnerable populations accessing credit institutions, since irregular income is hard to prove. Currently, 80% of the population is somehow barred from banking services given their low (or lack of) verifiable earnings; approximately only 9% of the population has access to formal credit services of the limited maximum amount (up to 450 USD) (author's calculations based on data from (ProDesarrollo Finanzas y Microempresa, 2019)). Savings held in a financial institution are usually non-existent, hence it is hard to access credit.

An adequate discounting alternative for Mixteca could be access to development banking services for productive uses. Governmental support would also play a role in providing conditions for beneficiaries of loans and regulating the financial market so that interest rates could be accessible to a bigger share of the population.

In the context of this work, the criterion *O. Financial market in rural economy* is used to assess this rule (see Table 8 in Chapter 0).

7.5.3 Rule 4: Fair (inter)national economic framework conditions

Sustainable practices allow producers and consumers to express preferences for a more just and environmentally healthy relationship. The international rhetoric on sustainability has not permeated down to local Mixteca, it is still a foreign concept. The first step of global integration for Mixteca would be to integrate within the state market. But a successful integration could take place only when an organized society promotes the participation of capable inhabitants to work for the economic development of the region. The adaptation of a local financial system, production, education, capacity-building and reduction of remittances could shape new opportunities for development in the area.

Lack of funding availability in Mixteca limits the population's capacity to adopt new technologies, invest in production improvement / increase or key assets, land purchase, skill-building or hiring employees. To avoid labor costs and expenses, family members usually perform underpaid productive labor; in the case of children, they are forced to work to "compensate" for any lack of productivity or work quota for their parents, thus sacrificing school time in unpaid jobs under poor conditions. The human development implications of participation in economic activities should be integrated under fair framework conditions.

Policies, laws and institutions in the region could help to create an enabling environment for sustainable livelihoods by being part of the reference context of a fair national context. Limitations and opportunities for fair participation should be analyzed for the extent of their impacts. The focus to improve local conditions and the wellbeing of communities in Mixteca should be the core of the analysis. The population, local producers and authorities should coordinate and adjust their economic decisions within a framework of an articulated institutional agreement based on fair prices considering the social and environmental counterparts.

In the context of this work, the following criteria are used to assess this rule: *D. Source of income* and *G. Job and earnings* (see Table 8 in Chapter 0).

7.5.4 Rule 6: Society's ability to respond

The first step toward reducing our ecological impact is to recognize that the environmental crisis is less an environmental and technical problem than it is a behavioral and social one (Wackernagel and Rees, 1998). It can therefore be resolved only with the help of society, whose goal to preserve natural capital is the bottom line of their efforts.

Mixteca in its status quo is already facing ecological challenges, thus a socioeconomic change is required. The loss of environmental value is still seen as an unfortunate but mostly necessary “trade-off” against economic growth - or better said, survival - in the region. Mixteca is a fully dependent sub-system within the ecosystem of the area. To develop a fulfilling and sustainable way of living within nature, it is necessary to rethink the interaction of communities with their ecological systems. The traditional focus in the region has been more on social issues than on environmental ones, probably because social concerns have always been more acute. Nevertheless, through decades of stagnation, there is a tendency in the area to normalize the status quo: the area lies in a poverty status: e.g. lack of basic services, poor education, bad housing, scarce healthcare within their poverty conception, natural resources have also been meager and will continue to be so. A direct correlation between the inhabitants and the depletion of the natural environment is overlooked or justified by the argument *ad populum* that urban areas or bigger regions have caused the main destruction; in part this is true, nevertheless, their own resources’ direct impact is somehow neglected. There is also a lack of support from local authorities as well as from state or national policies, so a sense of direction and resonance is not in place.

Institutional measures - education, awareness campaigns, effective governmental planned actions for the long-term future - are still not in place, and society in Mixteca has not yet developed its resonance capacity. Although the changes are perceived in the natural environment and respect (mainly from indigenous groups) is perceived, society is not ready to adjust to disturbances in the environment which have potentially major consequences in the future. The population still needs to clearly see the relationship between a lack of action and the impacts in the environment so that the capacity of resonance can be developed. Hence, it is proposed to monitor and control the level of air emission pollutants.

Inhabitants in Mixteca sell craft ornaments which are undervalued; a consciousness that elements such as water and resource scarcity, soil and air pollution, alterations in their habitat, ecosystem damage, and a lack of proper infrastructure to develop their activities is not linked to the end product price. Nevertheless, even if they had this awareness, the buyers do not have sufficient consciousness of these impacts, and would most likely not be willing to pay the associated costs. If inhabitants in Mixteca developed the ability to respond, they could be envisioning added-value activities for which capacity-building is needed. A plan for the mid- and long-term future would provide that sense of response to the current lack, which would extend in the future if no action is taken.

In the context of this work, the criteria *R. Environmental effects on population, S. Women's empowerment, B. Ethnic identification* and *D. Source of income* are used to assess this rule (see Table 8 in Chapter 0).

7.5.5 Rule 7: Society's ability of reflexivity

Reflexivity serves to increase knowledge about side effects in the actions of the different actors in politics, the economy and society. Reflexivity aims to reduce the short-term orientation or process perspective to create a basic willingness to support the cause of sustainable development. While Mixteca and the country are still far from general acceptance and widespread application of market-based environmental instruments such as environmental taxes, e.g., energy taxes, or emissions taxes, and the acceptance and dissemination of knowledge could and should be promoted to create reflexivity regarding the impact of human activities on the environment.

Ecological taxes and measures still compete and conflict with other basic needs in Mixteca, such as the use of resources to secure existence. The resistance to environmental programs that increase costs or prices might also impact factories or small producers, who look forward to getting cheap wages and employment in this region. In contrast, this could be seen as an advantage for the general population, who could link the benefits to themselves and see the impacts on the environment.

It can be expected that the population in Mixteca cares more about economic short-term impacts rather than the long-term outcomes in the diverse scopes: social, political, environmental, economic. This might prevent and delay action in the present. A short-term economic decision with an immediate payback profit will prevent long-term investments, e.g., solar PV system installation with a long-term benefit for the community. Hence, a long-term reflexivity orientation is required by civil groups or local authorities in the area.

Sustainability is still a foreign concept to society in Mixteca. Impacts of socio-ecological actions or lack of actions are not evaluated, hence the importance to stress the anticipation of the consequences. The recognition and acceptance of vulnerable groups' contribution to societal and economic life in Mixteca is the first step towards reflexivity, therefore criteria such as those to preserve and increase the native languages in the area; women's formal employment, and investment in renewable energy research are measures that function to promote reflexivity in the area.

In the political arena, there is the Green party aligning their interests to every presidential administration by siding with the political party most likely to win. The current promotion of fossil fuels which undermine the environment, and the prioritization of corporate interests over public and environmental ones, are examples of stances which have impeded the design of common reflexivity strategies at policy level, so sustainability is still a long way from being institutionalized. Accusations of corruption and unlawful political practices compromising environmental values (the push for legislation that addresses deforestation, pollution, animal rights, water and waste management), still prevail (Rios, 2021) and prevent society exerting its reflexivity. Those lacks in the legislation are (ab)used by private companies and factories to discharge wastewater without treatment, release emissions into the atmosphere and use natural resources at their discretion in sub-urban or rural areas such as Mixteca, without penalties or sanctions, favoring the "economic savings" to their own interest. Most industries strive for a rather soft environmental policy.

In the context of this work, the following criteria are used to assess this rule: *B. Ethnic identification, J. Investments in energy research, S. Women's empowerment* and *C. Education* (see Table 8 in Chapter 0).

7.5.6 Rule 8: Society's ability to govern (steering ability)

In Mixteca, elderly people are considered to be a respected, wise group of people who have reflected and hold experience on many community issues and concerns, but above all, they hold knowledge of the past and present changes in the socio-economic life of the community. Their age and wisdom position them as traditional leaders since they hold the knowledge about the existing local groups and organizations, without being bound to a civil responsibility position. Their position is strengthened within the native groups who traditionally hold a hierarchical structure of authority and power in terms of governance. Any major decision related to the community ought to be first addressed through them. Another reason for addressing the ancestral authorities is that their traditions and ascendants have entitled them to be the custodians of the community's natural resources. Respect for and connection to the ecological system are tied to the social system, so traditional authorities must be fully involved in the implementation of programs and projects in their areas of jurisdiction in order to enhance the legitimacy and pertinence of those projects and programs to the local people.

In the vast majority of communities in Mixteca, religious leaders (predominantly from the Roman Catholic church) contribute to the steering ability of the community. They are not only spiritual leaders but contribute to the physical development of the community. Sometimes they are also involved in the decision-making process of the community. Religion is a cultural aspect of the communities which is embedded into their style of government, and whose practices shape daily life and provide hope and significance. An example is the community's patronal festivity, a popular Catholic event that serves as a space that furnishes cultural elements for building the community's identity.

In Mixteca, community leaders appointed by the inhabitants are those who can motivate and engage inhabitants in community projects leading to the development of the area, and they are the ones who participate in civil political positions. Community engagement with the local leadership is fundamental for a good decision-making process whose origin is within the locality. In a bottom-up approach, these local leaders could build a relationship with the state and federal officials to advocate for the locality, ensuring robust public outreach by involving community members. Community engagement, along with an open dialogue, joint problem-solving, and collaborative action among community members can provide the steering ability in the local region. This also helps to increase their capacities to manage unforeseen situations and improve the use of shared resources, setting the path to a sustainable future.

In the context of this work, the following criteria are used to assess this rule: *H. Governance uncertainties, I. Governmental policies for integrated energy system,* and *P. Legal system* (see Table 8 in Chapter 0).

7.5.7 Rule 9: Society's ability of self-organization

Local organization plays a vital role in every aspect of local life in Mixteca communities. The communities' ability of self-organization is a process that goes beyond a top-down approach of leader and followers; it is instead, a partitioned organization where tasks are distributed among the community members who are able to make decisions from social, economic, and environmental perspectives, thus local organization plays a vital role in structuring and implementing localized plans and policies for governance.

As discussed in chapter 0, *Tequio* or community work is an important practice of community service in Mixteca. It is an effort to coordinate members of the community that seeks to cover specific individual needs or solve collective problems. This exercise activates a social articulation mechanism that consists of mutual support among the members of a community to achieve certain objectives that benefit all those who participate.

The capacity of the community to self-organize allows its members to develop autonomy, ownership, involvement and commitment with the entire community, setting a step into sustainability. It also promotes a culture of trust and awareness for the global aim rather than personal gain. The culture of openness and trust provides the backbone for people to feel safe in expressing new ideas (Patiño Tovar, 2003) and be part of an active community.

In the context of this work, the following criteria are used to assess this rule: *F. Population acceptance of renewable energy plans and participation,* and *T. Community organization* (see Table 8 in Chapter 0).

7.5.8 Rule 10: Balance of power between societal actors

The different and frequently divergent interests of actors interacting in Mixteca are barriers to exercising free, objective decision-making processes in favor of a beneficial socio-ecological interaction. The lack of commitment to reconcile these interests - mostly about economic power - in favor of the general population and the most vulnerable sector, has been the main impediment to development and a sustainable future in Mixteca. The forces of power in the region are usually aligned towards those with the most economic or political influence, setting aside the population's real needs or environmental requirements. These barriers include a central short-term orientation from all actors involved looking forward to "immediate" results. An institutional balance of power does not formally act in the area. A conflict-regulation strategy is usually driven through those who hold the economic power in turn: could be private investors, politicians, concealing an alleged benefit to the population, usually in prejudice of the ecological system. A recognized strategy with a proper balance of power among all actors is currently nonexistent.

The decision-making process in Mixteca is also hindered by a lack of information or access to it. It is usually the population, holding a generally low level of education, which is disfavored and affected by an underrepresentation of their interests when dealing with other actors. Institutional access to open communication between the societal actors is not striven for in the area. Hence, there is an unequal scope for action and influence that limits the degree of power of each participant during the decision-making process.

In the context of this work, the criterion *M. Cooperation between government, private investors, NGOs* is used to assess this rule (see Table 8 in Chapter 0).

"Without restoring an ethos of social responsibility,
there can be no meaningful and sustained economic recovery"

— Jeffrey D. Sachs (2012)

8. Scenario results presentation[4]

This chapter (0) along with previous chapters 0 and 0, and the subsequent chapter 0 belongs to Part 4 of the dissertation; the application of the method and results presentation (see chapter 0). The following sections present the first results of the application of the *Scenario-based sustainability assessment* approach (chapter 0). Section 8.1 unfolds the impacts of the descriptors within the system and the tight interdependencies among descriptors (see Table 8 in Chapter 0). Section 8.2 exhibits the eight consistent scenarios resulting from the Cross-Impact Balance analysis and their arrangement into two contrasting clusters, one optimistic and the other with a pessimistic outlook. Section 8.3 analyzes the synopsis, "Back to the XIX century", based on the cluster of scenarios 1, 2, 3 and 5, due to the worsening of the living conditions in Mixteca compared to the status quo. Section 8.4 reflects on the storyline, "Hope for a better future", whose cluster of scenarios 4, 6, 7 and 8 foresees a promising future for Mixteca. Section 8.5 analyzes and provides a comparative summary between both clusters of scenarios. Section 8.6 reflects on the results and presents a discussion linked to social-ecological systems theory to explain concepts such as transformability and basis of attraction.

8.1 Driving forces

In order to select the role of the descriptors in the system, an evaluation of their impacts is a helpful way to consider the driving forces. A driving force is a descriptor which exerts influence on other descriptor(s), usually called an active descriptor. In contrast, a passive descriptor does not exert any influence on other descriptors, rather it is influenced by other descriptor(s). Plotting all impact values - whether active (y-coordinate) or passive (x-coordinate) - in a chart obtains the system grid shown in Figure 26. Active sum shows the number of descriptors which are affecting another selected descriptor. Passive sum accounts for the number of descriptors which are influenced by another descriptor. A high active sum and a comparable low passive sum indicates a driving force; in Figure 26 they are situated at the top left of the chart. Descriptors with a low active, but high passive sum are those which are more reactive to changes of the system than actively influencing it. They are mostly situated in the lower left part of the chart. A third category represents those descriptors with no large discrepancies between active and passive sum; they are influencing a good part of the system under review, but they are also very much influenced by other descriptors. Weimer-Jehle refers to this type of descriptor as usually connected with the potential emergence of complex system behavior (Weimer-Jehle).

4 This chapter is strongly based on the article "Challenges for energy transition in poverty-ridden regions – the case of rural Mixteca, Mexico" (Oviedo-Toral et al., 2021).

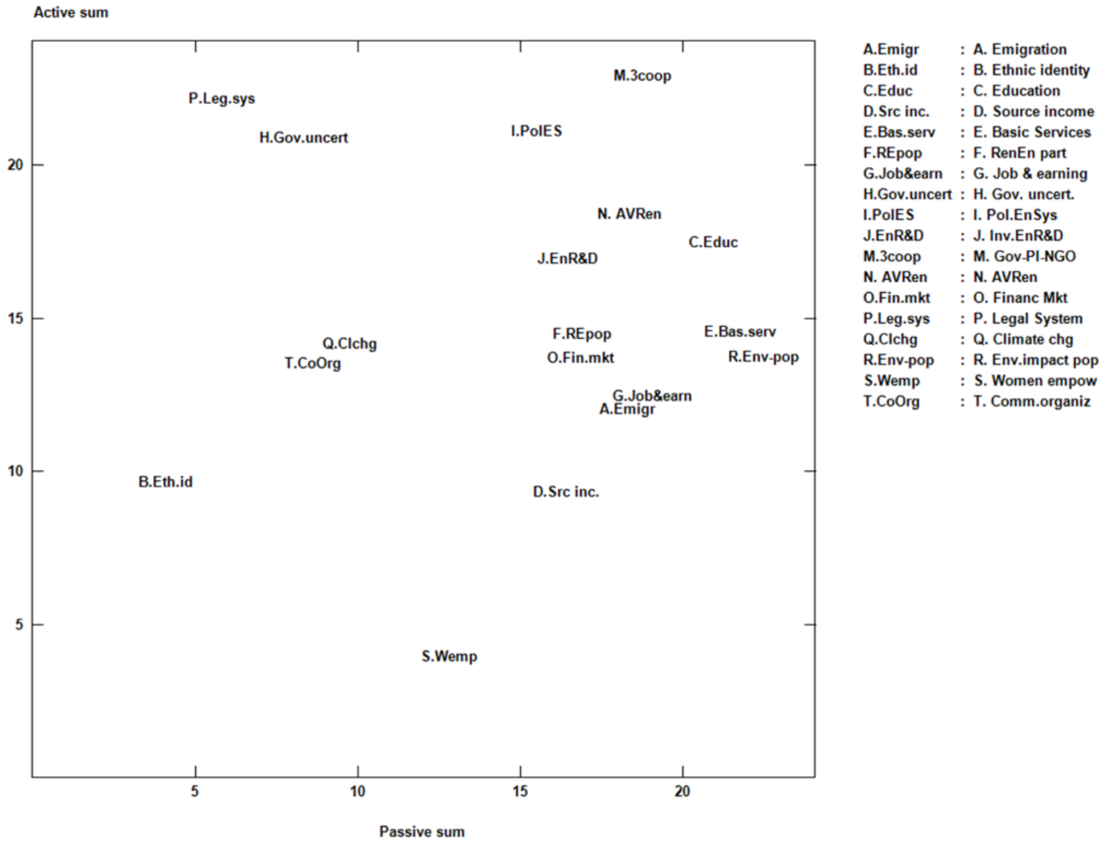


Figure 26. Active–passive positions of the descriptors.

Considering this structuring of the descriptors, the main driving forces are *P. Legal system* and *H. Governance uncertainties*, which exert more control than those at the right or bottom and are able to control the system in an effective way. In addition, as a third driving force, we identified *Q. Climate change*. That descriptor has a special position in the system, as it is influenced by the behavior of the system. However, the development of that descriptor is also determined by factors outside of the system under review.

From Figure 26, we identify clusters of relations additional to the main drivers of the system. Highly-connected descriptors are *M. Cooperation between government, private investors, NGOs; I. Governmental policies for integrated energy system*; *N. Added Value creation from the renewable energy sector*; *C. Education*; *J. Investments on energy research*. These five descriptors in the top right domain in the figure are factors exerting strong influence on the system and, at the same time, sensing strong influence. Of significant relevance are descriptors *M. Cooperation between government, private investors, NGOs* and *I. Governmental policies for integrated energy system*. These two are strong drivers of influence and they are also highly susceptible to being influenced. Further details on the specific influence exerted in the scenarios follow in the next sections.

Another cluster of relations exerting active influence and at the same time receiving influence are *F. Population acceptance of renewable energy plans and participation*; *E. Basic services access (water, electricity, drainage)*; *O. Financial market in rural economy*; *R. Environmental effects on population*; *G. Job and earnings*; *A. Emigration*. This cluster has less active strength on the system than the previous cluster, but is still able to impact the outcomes of the system, and at the same time is driven by the dominance of other(s) descriptor(s).

It is particularly noteworthy that most of the descriptors are located in the upper half of the diagram, related to an effective force on the system (active descriptors).

Those three factors positioned in the lower part: *B. Ethnic identification*; *D. Source of income*; *S. Women's empowerment* shape the system in a lesser way. Especially *D. Source of income* and *S. Women's empowerment* are more dependent descriptors following the guide of the rest, with not much influence on the events in the system. It is particularly noticeable that descriptor *S. Women's empowerment* has the lowest active-passive relation, which means it is the descriptor that can least influence the system and yet is affected by the influence of the other descriptors. Descriptor *B. Ethnic identification* has one of the lowest active relations and at the same time, the lowest receiving influence, hence it has minor impacts on the rest of the descriptors.

From Figure 26 a narrow interaction can be seen between most of the descriptors, whose influence will result in the scenarios presented in the next section. The tight interrelationship among all the descriptors is an intricate web, as shown in Figure 27. The arrows in the figure indicate the direction of the influences[5].

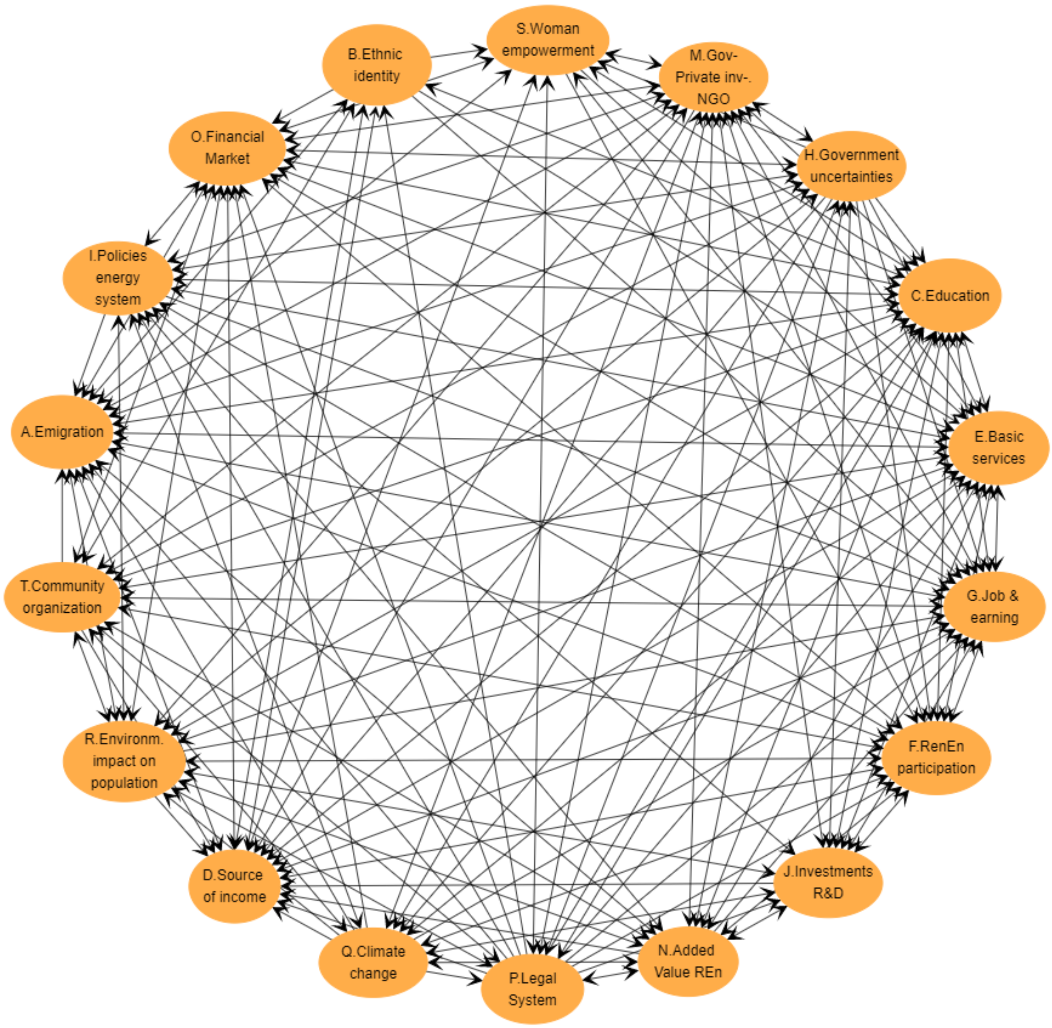


Figure 27. Interdependencies among descriptors.

[5] The format of Figure 27 was modified with respect to that of (Oviedo-Toral et al., 2021), however, the interdependencies and descriptors remain the same.

A detailed understanding of each descriptor’s role within the system, reflecting the direct and indirect influences in a scenario-based arrangement, will be analyzed in following sections.

8.2 Characterization of Clusters

As outlined in section 5.2, a total of eight consistent scenarios were calculated (see Figure 28). Given the structure of the scenario outcomes, it can be observed that the eight scenarios can be organized in two groups for a finer analysis. Consequently, they have been arranged into two Clusters, as they shape very different outcomes / future developments.

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 5</th><th>Scenario No. 4</th><th>Scenario No. 6</th><th>Scenario No. 7</th><th>Scenario No. 8</th></tr>
<tr><td>A. Emigration:
A2 perm w/bond</td><td colspan="3">A. Emigration:
A3 permanent emigration without bond</td><td colspan="4">A. Emigration:
A1 return emigration</td></tr>
<tr><td>B. Ethnic identity:
B2 high</td><td colspan="3">B. Ethnic identity:
B3 pluricultural</td><td colspan="4">B. Ethnic identity:
B2 high ethnic identification</td></tr>
<tr><td colspan="4">C. Education:
C1 less than 5 years</td><td colspan="4">C. Education:
C2 from 5 to 9 years</td></tr>
<tr><td colspan="2">D. Source income:
D2 remittances</td><td colspan="2">D. Source income:
D3 remittances plus labor</td><td colspan="4">D. Source income:
D1 labor</td></tr>
<tr><td colspan="4">E. Basic services access (water, electricity, drainage):
E1 no access to any service</td><td colspan="3">E. Basic Services:
E3 partial access to services including electricity</td><td>E. Basic Services:
E4 all</td></tr>
<tr><td colspan="4" rowspan="2">F. Population acceptance of renw energy plans and participation:
F2 limited to labor</td><td colspan="4">F. Population acceptance of renw energy plans and participation:</td></tr>
<tr><td>F3 econ.contrib.</td><td>F2 ltd to labor</td><td colspan="2">F3 economic contribution</td></tr>
<tr><td colspan="4">G. Job and earnings:
G3 no secure job and below minimum wage</td><td colspan="4">G. Job and earnings:
G2 stable job above minimum wage</td></tr>
<tr><td colspan="4">H. Governance uncertainties:
H3 strong uncertainties without growth</td><td colspan="4">H. Governance uncertainties:
H1 low uncertainties</td></tr>
<tr><td colspan="4">I. Governmental policies for integrated energy system:
I1 restrictive policies on new energy systems</td><td colspan="4">I. Governmental policies for integrated energy system:
I2 supportive policies on new energy systems</td></tr>
<tr><td colspan="4">J. Investments in energy research:
J1 low investment or none</td><td colspan="4">J. Investments in energy research:
J2 high level of investment</td></tr>
<tr><td colspan="4">M. Cooperation between government, private investors, NGOs :
M1 nonexistent or low</td><td colspan="4">M. Cooperation between government, private investors, NGOs :
M3 excellent</td></tr>
<tr><td colspan="4">N. Added Value creation from the renewable energy sector:
N1 nonexistent or very low</td><td colspan="4">N. Added Value creation from the renewable energy sector:
N2 existent or good</td></tr>
<tr><td colspan="3">O. Financial market in rural economy:
O3 no access to formal or informal market</td><td colspan="5">O. Financial market in rural economy:
O2 access to informal financial market</td></tr>
<tr><td colspan="4">P. Legal System:
P2 aggravated</td><td colspan="4">P. Legal System:
P1 law enforcement</td></tr>
<tr><td colspan="4">Q. Climate change:
Q1 high impact</td><td colspan="4">Q. Climate change:
Q2 low impact</td></tr>
<tr><td colspan="4">R. Environmental effects on population:
R1 high impact</td><td colspan="4">R. Environmental effects on population:
R2 low impact</td></tr>
<tr><td colspan="3">S. Women’s empowerment:
S1 limited or no empowerment</td><td>S. Women empow:
S3 partial</td><td>S. Women empow:
S2 fully attained</td><td colspan="2">S. Women’s empowerment:
S3 partial</td><td>S. Women empow:
S2 fully attained</td></tr>
<tr><td colspan="7">T. Community organization:
T2 limited to labor</td><td>T. Comm. organiz:
T3 econ.contrib.</td></tr>
</table>

Figure 28. Consistent scenarios identified via CIB.

The Synopsis under Cluster 1 consists of scenarios 1, 2, 3 and 5, whose storyline, “Back to XIX century”, explores the deterioration of social, economic and political conditions in Mixteca. Cluster 1 describes a situation which is characterized by an aggravated legal system with a strong uncertainty regarding governance and no (economic) growth perspectives. Additionally, the region is highly affected by climate change. The combination of these driving forces depresses the economic situation of the population, reducing the incentives to invest in education and decent jobs in the region, and promotes emigration as unskilled workers. A lack of access to formal financial markets also hinders investment in decent jobs. The bad economic situation also impedes investment in basic services, further deteriorating living standards and the prospects of remaining in the region. In respect to the energy system, the traditional orientation of energy policies prevails, thus discouraging investments in solar energy sources, as well as in the participation of civil society.

These conditions are comparable to those experienced by past generations during the early XIX century, where the country started its transition as an independent society characterized by widespread poverty and lack of opportunities in rural areas, that is the reason this cluster is named after the XIX century conditions.

Synopsis 2 consists of the cluster of scenarios 4, 6, 7 and 8, whose storyline, “Hope for a better future”, contrasts with synopsis 1. It envisions a future with an improvement of social, economic and political conditions, where the low uncertainties in governance combined with law enforcement in the legal system provide an improved framework, with stable sources of employment and income generation in the region. The support of renewable energy policies for energy transition increases the potential of investment in these projects, not only from cooperation with entities outside the region, but from the population itself, who will be supportive and willing to self-finance its projects, aiming for a self-sufficiency of energy supply. Therefore, contrasting with Synopsis 1, self-generation of jobs and income within the communities will be a milestone aspired for and achieved, thus avoiding emigration, improving the chance of education, and increasing the possibility of lower impacts from climate change with lower impact on the population. Hence, a likely improvement in the quality of life would reduce poverty in the hope for a better future.

The overall appreciation is that Cluster 1 differs from Cluster 2 in a divergent pathway; the main drivers such as *P. Legal system* and *H. Governance uncertainties* produce opposite outcomes that lead to either hindering or promoting appropriate development conditions in the area.

8.3 Cluster 1, Synopsis: “Back to the XIX century”

Synopsis 1 is characterized by the aggravation of the legal system, whose ineffective judicial system (descriptor P) will affect the region. Corruption and impunity will undermine the rule of law; a situation comparable to the status quo in Mixteca. Using Mexican data, since specific data for Mixteca are not available, on a scale of 0 (high corruption) to 100 (no corruption), Mexico achieves just 31, i.e., reaches the place of 124 out of 180 analyzed countries (see chapter 0)(Transparency International, 2022). In the context of rampant corruption, impunity and the weak rule of law, the security crisis and the aggravation of the legal system (state P2) in Mixteca will be a tough challenge. Another dominant driver in this synopsis is the strong uncertainty in governance (descriptor H). Conflicting policies, programs, and communication between national and regional level will contribute to increased uncertainties. Insufficient state capacities, both geographically and across policy sectors, will presumably undermine the effective and coherent implementation of policies. As a result, the energy sector will be exposed to hazard; the transition from a fossil fuel economy to the use of solar PV energy sources sees a tough future under synopsis 1. The future under this scenario challenges economic growth, affecting the weak economy in Mixteca.

The worsening of the legal system, combined with strong governance uncertainties, would exert a powerful negative influence on adopting local policies to support solar energy systems in the region (descriptor I). It will reverse the renewable path the country had envisioned and committed to in 2012, hindering significantly the integration of local solar PV energy projects, and restricting its future development (state I1), therefore, scarce investment in research into renewable and clean energy (mainly solar) will be the future trend, Mixteca will not be able to profit from (descriptor J). Under these circumstances, investments in research and development of solar energy will not be a priority (state J1); on the contrary, Mixteca will join its future in dependence on fossil fuels.

Because of the stagnation of renewable energy policies, the future value added of solar PV energy (descriptor N) will be not considered (state N1) under this future trend. Notwithstanding the high solar radiation levels in the region, the lack of support for renewable energy policies would provide unequal conditions to create value-added on solar PV projects. This situation would lead to low interest and participation from the population (descriptor F), who would be limited to providing a workforce (state F2) in the rural area to contribute to PV energy aspects. Thus, societal and economic conditions could inhibit the technological transition in the territory.

Prioritizing fossil fuels will also undermine the cooperation (descriptor M) between Government, private investors and NGOs on solar PV energy projects, discouraging investments due to the meager value added (state M1). The decision to favor fossil fuel generation over renewable energy will also put Mixteca on a path that is even more inconsistent with mitigation measures to avoid a strong impact from climate change. Under the conditions shown in Synopsis 1, Mixteca will be highly vulnerable to the impacts of climate change (state Q1) in the form of more extreme weather patterns such as rise of temperature, heat waves, unusual rain seasons, and acute and longer droughts (Gobierno del Estado de Puebla, 2011), which will unavoidably aggravate existing social and economic inequalities.

These adverse conditions from climate change will severely affect the low-productivity from agricultural jobs, tending livestock, hauling water and processing agricultural products. It will also promote a high impact on population (descriptor R, state R1) who would seek to leave the area, mainly outside of the country, as a way to overcome the intensified poverty in Mixteca. Under these circumstances, the trend G3 "no secure job and below minimum wage" is a consequential outcome. The uneven distribution of income is highlighted in low-skilled and rural Mixteca, which has a history of unequal job opportunities (CONEVAL, 2018a).

Due to the scarcity of resources and opportunities to make a living, rural Mixteca will experience persistent inequity in education under Synopsis 1. The marginalized population will have no choice but to give up education and devote their time to seeking an income to sustain themselves, or to emigrate. As a result, the level of schooling under Synopsis 1 is expected to be low, under 5 years (state C1), which is not enough to complete basic education.

Migratory flows will be a pressing issue reflecting the lack of economic growth, and thus low perspectives for decent jobs. However, Cluster 1 allows for two different situations: emigrants will have a strong bond to their region (state A2; scenario 1) or not (state A3, scenarios 2, 3 and 5). The latter state describes the status quo in the region where a strong partial dependence of remittances is persistent. Even with no bond to Mixteca, remittances will play an important income source in the region. However, the relevance differs between scenarios 1 and 2, and 3 and 5. The first two scenarios 1 and 2, see financial transfers as the main income source (state D2); the other two scenarios 3 and 5 show a combination of remittances with labor income to compensate the minimum wage and support domestic consumption (state D3). The dependence on the remittances is also a reflection of low job earnings (state G3) in the region.

The region will also have higher percentages of deprivation in access to basic services (state E1) such as water, electricity and drainage that encompass the fulfillment of their social rights. This outcome is also a consequence of the lack of an adequate level of education, which prevents the inhabitants from having the knowledge to exert their rights of access to basic services coverage.

Given the worsening conditions in the area, formal financial services will not be provided, since the security demands for loans by the formal sectors are too high for the local population, and thus the establishment of a formal banking sector is not profitable. The population may have access to the informal financial markets (state O2; scenario 5) or no access to any financial markets (state O3; scenarios 1-3). This depends on the economic situation in the region, which could differ between the scenarios.

The depressed economic and social situation with (mainly male) emigrants leaves no (State S1; scenarios 1-3) or limited human and financial resources (State S3; scenario 5) to empower women, although the necessity is obvious. Women are more likely to be engaged in low-productivity activities and work in the informal sector or in unpaid family jobs, and less likely to move to the formal sector compared to men; therefore, empowerment among women will be highly limited. Scenario 5 in Cluster 1 is the only one which envisions a partial empowerment and women's participation in decision-making processes (state S3), probably related to an attempt to move to a higher level of full empowerment.

On Synopsis 1, most scenarios are inclined to the pluricultural identity (state B3) obtained through the interaction of two or more communities inside the national territory, or outside of it as a consequence of the migratory flow (Fox, 2006). The pluricultural identity is also promoted by the interaction of the communities in the vicinity during the early years of education of children. Only one scenario, scenario 1, reflects the high ethnic identification bond that permeates through returning emigrants, as well as through those who keep a permanent bond with their ethnicity (state B2). This sense of belonging to an ethnic group promotes community support, mostly on the labor force. Ethnic identity is very much linked to emigration patterns, but it also maintains a relationship with income sources; while pluricultural status in two scenarios (3 and 5) can obtain income from remittances and labor, the other two scenarios depend mostly on remittances due to meager job opportunities and low earnings.

Despite the described main pathway where most scenarios are immersed, some variations are also found that could partially lead to different states within the same cluster for some affected descriptors. For instance, scenario 1 foresees that although there is permanent emigration in Mixteca, the strong ethnic identification (state B2) of the emigrants will lead into a bond with their families and / or communities of origin, hence state A2 is a reasonable aftermath. These two descriptors variants are not enough to change the main pathway of Cluster 1, *A. Emigration* being a rather higher passive descriptor than active, and *B. Ethnic identity* being low passive more active but with limited influence in the overall direction of the system. Hence, scenario 1 does not change the progression of the pathway.

Another variant within Cluster 1 is presented in scenario 5, where the future source of income could envisage remittances plus labor (state D3), the access to labor opportunities may open the possibility to higher income, hence access to the informal financial market (state O2), which in turn could partially empower women (state S3). Empowered women could also gain access to additional sources of income; consequently, a feedback loop might potentially also take place. This variant could also be seen as follows, partially empowered women (state S3) may possibly access informal financial markets (state O2), so income sources could also be the result of labor plus remittances (state D3). The triggering action is not clear given the non-linear reality caused by the feedback loops. The integrative approach from CIB couples social interactions in possible non-linear relationships (Weimer-Jehle et al., 2016). Nevertheless, these variants and movements within the cluster are not enough to exert a major influence in the pathway, as they do not exert significant influence on the drivers of change (descriptors *P. Legal System, H. Governance uncertainties*, and *Q. Climate change*), consequently, the main outcome - more poverty - would remain unchanged.

In summary, Cluster 1 envisions a path of increased poverty, lack of opportunity for development, persistent emigration and a society's lack of hope regarding its own future. A solar PV energy transition will bring neither success nor better quality of life in Mixteca under this synopsis.

8.4 Cluster 2, Synopsis: "Hope for a better future"

A future with low uncertainty regarding governance (state H1) describes a situation in which the government will have developed the capacity to exert effective and efficient decisions, ensuring a proper and informed process as well as stakeholder involvement, hence decreasing the risk of uncertainty among the population. Policies will be open and transparently handled, offering the communities in Mixteca an understanding of the local decisions taken. It will also maintain their focus, and address issues in an effort to avoid stagnation and provide certainty regarding the local government commitments, regardless of political administration change. Therefore, low uncertainty (state H1) about future government decisions and potential for economic growth would lead the way to a better future in the region.

A priority of the government will be to eradicate or diminish corruption through an enforced legal system (state P1). To accomplish this objective, on all governmental scales authorities will address effective transparency and accountability procedures to reach a convincing law enforcement.

In this Cluster (2) of scenarios, the energy transition plays a structural role compared to Cluster 1, in achieving Mixteca region's potential. To make use of the principally good conditions of high solar irradiation levels for installing photovoltaic systems, the energy policy will provide a system of supportive schemes, such as allowing clean energy preferred access to the national grid, subsidizing investments of PV infrastructure, guaranteeing selling prices, capacity-building regarding generation, controlling, maintaining and marketing of renewable energy, and reinstating energy auctions (state I2). The encouraging legal and economic conditions promotes the investment in PVs, leading to lower energy costs and better availability of electricity. Its generation capacity will be more competitive than gas and coal by a significant margin, and will increase its attractiveness as energy storage solutions become prevalent. The good conditions will attract two types of investor with different aims. The primary aim of one type of investor is to provide affordable electricity to the industry clusters in Puebla state and beyond, with less interest in supplying to the region. With the transition of the Mexican economy and a globally shrinking oil demand for Mexican crude oil (DNV GL Group, 2017), the new harvest solar alternative would provide support as an alternative source of revenue. The second group of investors are locals. Due to trust in the government and good general economic conditions, the inhabitants start to invest in PVs, with the aim to improve their own supply of electricity, and potentially the competitiveness of their local industry. Supply to nearby communities with higher population will be possible, but is not the focus of these investors. The momentum of the second group of investors depends largely on the acceptance of the population regarding renewable energy plans and participation (descriptor F). This ranges from willingness to contribute economically (state F3) to providing “only” labor support (state F2). The good conditions will also lead to a high level of investment in solar PV energy development (state J2).

The development of the electricity system will be accompanied by a positive value added (state N2). Due to the high solar radiation levels combined with a supportive economic environment, investments in PV technology will provide value added to the region, which will impact positively on innovation efforts or education (Warneryd and Karltorp, 2020). Since a high share of the investors are local, the value added will stay in the region, fostering local growth (Appunn, 2020).

The regional energy system in Mixteca would most likely exert a positive contribution on the national and global effort to mitigate climate change (state Q2). The magnitude could lead to a noteworthy decline in greenhouse gas emissions (GHG) beyond the national target of 25% that studies forecast for 2030 (Elizondo et al., 2017; IEA, 2017). Nevertheless, the situation of the climate in the region will be dominated by efforts outside the region. As a consequence, the environmental influence is expected to be handled without greater impact on the population (state R2), the communities will be better prepared to implement mitigation measures, such as adaptations in agricultural practices, or construction of houses in secure areas away from riverbanks or cliffs for example.

The positive impacts of the transformation on the region will also promote considerable partnerships between private investors, government and NGOs, who would support development projects in renewable transition (state M3).

The broad positive economic circumstances, fueled by the energy system transformation, will affect the labor markets, i.e., decent jobs with wage rates above the minimum (state G2). This would lead to an increasing relevance of labor income to total income, through which purchasing power is promoted in the course of time; better working conditions will be provided along with stable jobs (state D1). Under better working conditions, it is likely emigrants will decide to stay in the region, or even return from abroad (state A1). For some of them, working outside the country has provided the capital and skills to start small businesses, reflected in higher rates of self-employment upon their return to Mexico, compared to those with no migration history. Better working conditions in Mexico would bring an opportunity to avoid emigrants returning to the USA, reincorporating them into the economically-active population. This development enforces the relevance of labor income as the main income source.

With a higher and more reliable income, investments in schooling and infrastructure will gain importance. A longer schooling time (state C2) will not only mean building a skilled workforce, but also training future generations in raising awareness of sustainable development, as well as changing the population’s attitudes in everyday life. In particular, investments in PVs by local investors will increase the availability of electricity, which will also be used for productive purposes, by contrast with the current situation in Mixteca. According to the statistics (INEGI,

2010) most of rural Mixteca is connected to the grid, but availability for productive uses is rather limited. This will be accompanied by more investment in other basic infrastructures, since the financial situation of the communities, but also the organization of the communities, is improving. However, it is only in scenario 8 that all basic services are available (state E4) and the population is willing and able to support community-building with financial resources (state T3). In scenarios 4, 6 and 7 the access to infrastructure is limited (state E3) and the contribution of the inhabitants to community-building focuses on labor (state T2). The difference between both types of participation could lie in the degree of income. As long as the population is able to satisfy its basic needs, people will be likely to provide financing for the area.

Despite the positive economic situation, this will not overturn the impediments to accessing formal financial markets; that means informal organized credit suppliers will dominate the local financial market. The financial market in Mixteca will still be based on informal banking (state O2). Unlike scenarios 1, 2 and 3 of Cluster 1, where the population lacked access to any type of financing -i.e., neither formal nor informal, in Cluster 2, access to informal financial markets is likely to allow them to access loans for more productive uses to improve the standard of living. Savings will be used to buy assets: farm animals, land, or to build an additional room or an improvement to an existing part of the house, such as the roof or a wall. Financial inclusion will remain a challenge for rural communities in the future.

The strong commitment of women and the creation of women-to-women networks along the value chain and decision-making process, are vital for the integration of Mixteca's new energy technology at the community level, and ensuring the long-term use of these technologies (Heuër, 2017). These findings reflect women's essential roles as decision-makers, not only in the household but also in their communities. Women use their social network of relatives and friends to introduce products into their communities, so they have become trusted advisors, as with household energy. This empowerment reveals the need to involve women in energy projects and the need to incorporate gender into policies on energy transition (Batliwala and Reddy, 2003; Heuër, 2017; Permana et al., 2015). Although empowerment is foreseen in all scenarios of Cluster 2, the intensity differs between scenarios 5 and 8, and scenarios 6 and 7. Scenarios 5 and 8 see a partial empowerment (state S3), scenarios 6 and 7 see a full achievement (state Q2).

All four scenarios of Cluster 2 present a future with high ethnic identity (state B2). Ethnicity will be an important quality of the future communities in Mixteca. Returning emigrants will have the sense of belonging to their communities of origin through ethnic identity. Community organization is interrelated through labor, which in turn is promoted by the ethnic bond of the community itself.

A particular remark within this Cluster 2 is that scenario 6 differs from scenario 7 only in state *F2 Population acceptance of renewable energy plans and participation limited to labor*. The reason could be that one small disturbance in the system could have a significant impact to alter the stability of the overall system; one possible reason might be that the descriptor states cannot be defined with full precision, and interpretations of the context are still required (Weimer-Jehle et al., 2020), so a future representation is not completely possible. This situation may imply a low stability in the scenario, which is not strong enough to alter the main pathway, comparable to a movement from one basin of attraction to another in a social-ecological system (Walker et al., 2004) related to the low resistance of the system in scenario 6, as (François, 2022).

The contrasting states in most descriptors of Cluster 2 compared to Cluster 1 could be due to the effects on the main active drivers, states *H1 low uncertainties in the governance*, *P1 low enforcement in the legal system* and *Q2 low impact on climate change*. These have exerted a transformational effect, thus creating a new system influencing the rest of the descriptors. The main influence was primarily received by the states *I2 supportive policies on new energy systems* and *M3 excellent cooperation between government, private investors, NGOs*, which also exert driving effects to the rest, thus the overall divergent perspective of Cluster 2. The combination of these states has created feedback loops transforming the pathway of the cluster.

However, of the derived scenarios, scenario 8 differs from the other scenarios, in particular regarding basic services, women's empowerment and community organization. This scenario stands out from Cluster 2, relating more to the sustainable future Mixteca could aspire to, with the exception of descriptor *education* (state C2) which has still not reached an optimal state. One assumption could be that under scenario 8, Mixteca society has attained an effective implementation of the social value of energy (see section 2.1.3), where the availability of solar energy has improved the surrounding social aspects, positively impacting individual, household and community life (Miller et al., 2018). Besides full basic services access, women's empowerment and community organization - where projects can be financed by the members - highly relate to social improvement in Mixteca and go beyond energy provision. Then, it can be suggested that the effective social value of energy in scenario 8 can have a positive influence in poverty alleviation in the region.

In summary, Cluster 2 envisions a path where the social value of energy (see section 2.1.3) has improved the wellbeing of the community, showing a higher degree of economic development and better quality of life in Mixteca, because of a solar energy transition. A sense of prosperity in the area derived from stable jobs and earnings, as well as a perception of security regarding the energy system transformation, leads to the construction of a better and sustainable future.

8.5 Comparative summary

Both Clusters 1 and 2 show rather distinct developments, and thus distinct future situations. The reason lies in the distinct state of the main drivers, i.e., those with a large active or otherwise relevant position, and those which are highly interwoven. The main drivers are *P. Legal system* (P2 vs. P1), *H. Governance uncertainties* (H3 vs. H1), and *Q. Climate change* (Q1 vs. Q2). The highly interwoven descriptors are *I. Governmental policies for integrated energy system* (I1 vs. I2)*, N. Added Value creation from the renewable energy sector* (N1 vs. N2)*, C. Education* (C1 vs. C2)*, J. Investments in energy research* (J1 vs. J2), and *M. Cooperation between government, private investors, NGOs* (M1 vs. M3).

The clear separation between Clusters 1 and 2 is partly broken up by five of the descriptor states which overlap both Clusters. These relate to the descriptors *B. Ethnic identification* (state B2), *F. Population acceptance of renewable energy plans and participation* (state F2), *O. Financial market in rural economy* (state O2), *S. Women's empowerment* (state S3), and *T. Community organization* (state T2). However, these descriptors show passive positions or low active in the system (Figure 26). Their impact on development does not exert a compelling influence, rather they mostly receive effects from the other descriptors. Changes to these passive descriptors may not necessarily reflect a change in the pathway; the change is reflected within the Cluster but stays under the same pathway.

8.6 Scenario discussion

The divergent pattern of both Clusters 1 and 2 indicates the complexity required to set the transformation process of the region in motion – in both directions. A combination of multiple (relevant) descriptors is necessary for change. The picture may be explained through the concept of transformability presented by Walker et al. (Walker et al., 2004), as one of the attributes of social-ecological systems (SES). Walker et al. state that a new system will be established when ecological, economic, political or social conditions make the existing system implausible. Societal groups may find themselves trapped in an undesirable situation or development process, i.e., in a "basin of attraction", that is wide and deep. Small movements into a new configuration within the same basin are possible, but the outcome of the reconfiguration is not seen by the society as an improvement. An improvement which leads to a new basin, would require a large reconfiguration of the descriptors, which would define a new system with new states. Assuming, for the sake of argumentation, the situation described by Cluster 1 as the starting point of an undesirable situation, only a complete change of the most relevant descriptors would lead to the situation of Cluster 2. That is, the shift of those descriptors which exert the most influence within the system (the most active, thus drivers of change - see section 8.1) identified as *P. Legal system (*from *P2 aggravated legal system* to *P1* law enforcement), *H. Governance* (from *H3 strong uncertainties without growth* to *H1 low uncertainties*), Q*. Climate change* (from *Q1 high impact* to *Q2 low impact*) triggered *I. Governmental policies for integrated energy system* (from *I1 restrictive policies on new energy systems* to *I2 supportive policies on new energy systems*) and *M. Cooperation between government, private investors, NGOs* (from *M1 nonexistent* to *M3 excellent*). Consequently, these combined exerted influence on the rest of the descriptors, streaming social reconfiguration from Cluster 1 into the new Cluster 2.

Some SES persist in states of scenarios where the society cannot meet the basic needs of human wellbeing, or when the societal, environmental and political factors are degraded to an imminent loss of wellbeing; Folke refers to these states as "dysfunctional states" (Folke et al., 2009). If a worsening condition takes place in Mixteca, i.e., *P2 Legal System aggravates*, *H3 Strong governance uncertainties without growth*, *Q1 High impact on climate change*, then Cluster 1 would be likely to take place where extreme poverty would persist for extended periods. This system may lack the adaptive capacity to reorganize. To get out of the poverty trap, Folke suggests financial and / or political support, external supporting organizations (NGOs) and local development of innovation. These supporting components are present in Cluster 2 in the following states: *G2 stable job above minimum wage*, *H1 low uncertainties in governance*, *I2 supportive policies on new energy systems*, *M3 excellent cooperation between government, private investors and NGOs*, *P1 law enforcement*, hence the future of Cluster 2 seems to alleviate poverty. As Folke points out (Folke et al., 2009), transformational change involves shifts in perception and meaning, societal network configurations, patterns of interactions among different actors, power relations - not only political - and organizational and institutional arrangements. Transformations make use of crises as windows of opportunity and navigate societal transition from a regime in one stability landscape to another (Gallopín, 2006). Transformation involves novelty and innovation. The term innovation in this study is understood as the capacity to create new alternatives, ideas, opportunities for a change, or find solutions to existing problems; the introduction of new ideas into an existing process or system support the development of an adaptive capacity.

Periods of strong change driven by active social and ecological drivers, including *Q. Climate* *change*, *H. Governance* and *P. Legal system*, increase the likelihood of a perturbation[6] on the social-ecological change. In the absence of a determined direction or resilience (Folke et al., 2010), these changes are likely to trigger shifts from one state to another that may be socially either desirable or less desirable. A focus on resilience in social-ecological systems is needed to deal with the challenging new situation of social-ecological change. A poverty trap with persistent poverty as under Cluster 1, also reflects a loss of alternatives to deal with change. It is locked into persistent vulnerable conditions and external support is needed to make a shift. However, the measures might not be enough (G2, H1, I2, M3, P1). The breakout from a poverty trap depends on the innovation capacity within the system to create new opportunities; these are linked to sources of resilience and adaptive capacity to help people find ways to move out of the poverty cycle (Folke et al., 2009).

Although the concept is used for a static view of possible futures, principally the concept of basins of attraction could also be useful to explain possible developments of states over time within each Cluster, i.e., to derive possible trajectories. A trajectory would describe possible switches from one state to another, and in the longer term to a possible final state. For example, with an improving economic situation in the course of time, the opportunities to participate in installing a local community-based energy system – descriptor *F. Population acceptance of renewable energy plans and participation* – could change. As long as the economic situation is comparably bad, interested inhabitants would participate by offering their labor skills (state F2; scenario 6). If the income situation is enhanced, the inhabitants will provide financial resources (state F3; scenarios 5, 7-8). Such perturbations could occur continuously, thus leading to different complex trajectories. However, since the system evolves over time, the system could shift from the domain of influence of one basin of attraction to another until it reaches a stable landscape (Gallopín, 2006).

The adaptive capacity could be reduced with interactions that might seem abrupt changes toward a threshold that causes a temporary transition to a different state or basin of attraction; in Cluster 2 the transition in *S2 full women's empowerment* to *S3 partial women's empowerment* shows a loss of resilience and state shift, and as a consequence it is a shift from a desired state to one that is not desirable, although not irreversible; then, a perturbation in the system brings S3 again into S2, strengthening its resilience capacity. New sets of interactions come into play when a system in a basin of attraction crosses a threshold, leading to a flow of social influences under which each successive transformation is more resilient, in the sense that it would be more difficult to return to its original state. This can be seen in Cluster 1, state *S1 limited women's empowerment* moved to *S3 partial empowerment*. Thereafter, in Cluster 2 described above, the reorganization took place between S2 to S3 to settle in S2. This change occurred in the adaptation of a complex system (see sections 2.3.2, and 5.2) in which any change in the system triggers additional changes in its structure and properties.

The transition from fossil fuels-driven energy systems to solar PV systems brings a suitable opportunity not only for migrating technologies per se, but to reposition political and social dynamics through the configuration of the socio-technical system. New technology implementation as a driver of creative destruction of old regimes is necessary to create opportunities for more widespread dissemination of renewable systems (Geels, 2014). This new perspective would bring the opportunity to better understand how to enhance the potential for a

[6] Perturbations in SES are greater forces required to change the current state of the system away from the attractor (Walker et al., 2004).

successful transition by including civil society in the initiatives of transformation, using social interactions in the new configuration. This perspective should also include the analysis of weaknesses and interrelationships among the actors of the previous regime, which contribute to retaining it as a dominant actor. The shift to the new model of innovation promotes social interaction in the energy system, despite resistance to adopting and disseminating the new and promising configuration. The adoption of this model could be useful in the attempt to set the pathway to energy transition as the means to alleviate poverty in rural Mixteca. The restructure of the energy system could provide the opportunity to a just transition among sectors and institutions.

To achieve the transition, small-scale technological innovations should be available for those rural communities where consumers could become producers with their own power installations (Zalengera et al., 2015). This could foster the development of a social network related to energy, from the individual to the community level (Cabraal et al., 2005; Dóci and Vasileiadou, 2015). The potential of the effectiveness and impacts of these motivations in the creation of a sustainable local energy community could lead to a path to de-carbonization, decreased emigration, self-employment (Lowitzsch and Hanke, 2019) and self-sufficiency of energy supply (Cabraal et al., 2005), creating a sustainable environment in the area and a promising energy transition, while attempting less invasive power dynamics among actors.

This research is also useful to understand the societal dynamics and its interplay under social-ecological systems theory. This section 8.6 elaborated on the *Transformability* concept to explain how Mixteca might be trapped in the undesirable state of poverty and how a new system would require a large reconfiguration, in this case, the change from Cluster 1 to Cluster 2. Transformational change (Folke et al., 2009) involves shifts in perception and meaning, societal network configurations, patterns of interactions among different actors, power relations - not only political - organizational and institutional arrangements. Transformations make use of crises as windows of opportunity and navigate societal transition from a regime in one stability landscape to another. The transition from a fossil fuels-driven energy system to a solar-based system in Mixteca would bring a suitable opportunity not only for new technology implementation, but to reposition political and social dynamics through the configuration of the socio-technical system. This new technology implementation as a driver of creative destruction of old regimes (Geels, 2014), is necessary to create opportunities for dissemination of the renewable system. This new perspective would bring the opportunity to better understand how to enhance the potential for a successful transition by including civil society in the initiatives of transformation, using social interactions in the new configuration. The adoption of this model could be useful in the attempt to set the pathway to a sustainable energy transition as the means to alleviate poverty in rural Mixteca. The restructure of the energy system could provide the opportunity for a just transition among sectors and institutions. Providing energy access to alleviate poverty is more about understanding the importance of energy in the population's daily activities and supporting them to improve their wellbeing, rather than a transfer of technology. This is an opportunity to make a shift in rural communities.

The presented study emphasizes the relevance of analyzing the societal aspects affecting and being impacted in order to understand a renewable energy transition. This analysis is required to anticipate outcomes and adapt to undesirable consequences, as shown in Cluster 1, by exploring possibilities to advance a desired just transformation to the benefit of the population, as reflected in Cluster 2, in the aim to improve the living conditions in Mixteca.

"Only by educating people to a true solidarity will we be able to overcome the 'culture of waste', which doesn't concern only food and goods but, first and foremost, the people who are cast aside by our techno-economic systems which, without even realizing it, are now putting products at their core, instead of people"

— Pope Francis (2017)

9. Sustainability assessment results presentation

As introduced in section 2.2.2, a sustainable assessment is an approach to assist stakeholders in identification, measurement and assessment of potential impacts towards a sustainable future. This chapter (9) along with previous chapters 0, 0 and 0 belongs to Part 4 of this dissertation: application of the method and results presentation (see chapter 0). This chapter presents the results of the sustainability assessment for the scenarios introduced in chapter 0 as a result of the *Scenario-based sustainability assessment method* explained in chapter 0. Section 9.1 presents the articulation of the scenario results for the assessment, and introduces the traffic light system used as a tool for visualization, as well as the index and scale used for the weighting system. Sections 9.2, 9.3 and 9.4 explore the analysis of the criteria under each of the main sustainability rules concerning the three general goals of the ICoS (see Table 5, section 5.1). Section 9.5 exhibits a summary of the main goals assessment, as well as the re-examination of the first part of the second research question: "What could a sustainable future look like, and how could Mixteca achieve it?" as well as the third research question: "Is there a sustainable future that could promote poverty alleviation in the region?" (see chapter 0). Section 9.6 offers a sensitivity analysis to show the robustness of the results displayed in the assessment of the three ICoS goals. Section 9.7 displays the sustainability assessment related to the instrumental rules of ICoS. The chapter concludes with a summary of the instrumental rules assessment in section 9.8 and the re-examination of the second part of the research question addressed in section 9.5.

9.1 Articulating Cross-Impact Balance outcomes towards an assessment perspective

Based on the diagram presented in Figure 25 (see section 5.3), the adaptation of ICoS rules to the descriptors / criteria selection was performed and presented in chapter 0; targets and indicators were defined as a result of this process (see section 7.4). Chapter 0 delivered the operationalization of the previous contextualization which took place through the CIB algorithm. As a result, the array of scenarios as a base for the sustainability assessment was obtained. The following sections focus on the assessment of the criteria / descriptors defined for the system (see chapter 0). The following sections use the terms criteria and descriptor interchangeably (see section 5.3).

Some criteria were analyzed under more than one rule, and in some cases by more than one goal. Those are highly interrelated factors with chain reactions in the future scenarios. This condition could also be the consequence of the complexity of the descriptor in its interrelationship with the others, exerting and receiving influence within the system (see section 8.1). ICoS rules have been designed under an equal relevance conception whose theoretical principles of sustainability could be generally applied, nevertheless, at the operationalization level, once the rules are adapted to the particular context, priorities among rules or specific considerations are necessary. Despite the fact that several criteria have been analyzed by more than one rule, this procedure does not magnify or provide more significance to the related rule or goal. Within the ICoS framework, each rule has equal importance within a goal, and each goal has equal importance towards sustainability (see section 5.1.1). Two rules were not assessed for the Mixteca case (*sustainable use of non-renewable resources* and *avoiding technical risks with potentially catastrophic impacts* - see section 7.2), as they are not applicable.

The evaluation of the performance of the 18 descriptors / criteria according to the defined targets for 2050 was assessed based on the future scenarios. The *Scenario-based sustainability assessment* was performed with the aid of a traffic light scheme as a tool to visualization, using the colors red, yellow and green. This system is conceptually simple and easy to understand, where colors green and red are mostly used to indicate an acceptable or unacceptable outcome - or potential higher / lower fulfillment - respectively; color yellow is used for a minimal improvement or a non-regressive impact. This system has been successfully adopted for diverse subjects, e.g. risk management (Mahmoudi et al., 2018), seismology (Verdon and Bommer, 2021), food industry (McCarthy et al., 2014), to show potential future impacts fulfillment and monitor progress along a timeframe. This color-scheme is also useful to assess the level of accomplishment of the criteria meeting previously-defined goals.

In addition, to assist in the characterization of the areas of fulfillment, a relative index with a designed scale-up factor of 1:2 was used with a relative change kept constant. A sensitivity analysis varying the factors and scale changes did not show impacts in the end results, hence it was decided to use the relative change constant. The lowest score assigned was 5 points, the next one according to the scale-up factor is 10 points, and the highest score is 20 points. This scale is useful to aid the understanding of the assessment and provide a sustained visualization with charts at the end of each assessment. Based on the relation of the pretended indicator value for the future trend, if the target seems to exhibit a high probability of being missed, the color red and the lowest value of 5 points have been assigned. If the target is not anticipated to improve or would slightly improve, the color yellow with a value of 10 points is designated. An expected fulfillment of the future target is shown with the color green and 20 points are allocated.

During the operationalization, to keep the same priority among the ICoS sustainability rules, the total score for a specific rule was allocated among the number of criteria assigned to assess the rule. Thereby, when 2 or more criteria were evaluated under the same rule, the future expected value of the impact, according to this scale, is distributed among the number of criteria. For example, in Table 10 (see section 9.2), the rule *Ensuring satisfaction of basic needs* is assessed through three criteria*: A. Emigration, C. Education and E. Basic services access*. Using the example of criterion *A. Emigration*: In scenario 2, a pessimistic outlook is foreseen for scenarios 2, 3 and 5, hence the lowest score per the relative index described above is 5 points (in red) which shall be distributed among the three criteria; thereby, each criterion's lowest score is assigned 1.67 points ($1.66\overline{6}$ rounded up to the nearest 100th). The same procedure applies for a future with a low improvement perspective - yellow color - as in scenario 1; the total value of 10 points is distributed among the three criteria, resulting in an individual value of 3.33 points each ($3.33\overline{3}$ rounded up to the nearest 100th). Finally, for a positive outlook whose future could be qualified as sustainable with 20 points, each criterion is assigned 6.67 points ($6.66\overline{6}$ rounded up to the nearest 100^{th}). In the case of scenarios 4, 6, 7 and 8: If we add up the values of scenario 5 in the three criteria: *A.*

Emigration $1.6\overline{6}$ points, *C. Education* $1.6\overline{6}$ points, *E. Basic services access* $1.6\overline{6}$ points, the total value for the rule *Ensuring satisfaction of basic needs* is 5 points. The calculation for the rest of the assessments follows the same procedure.

It should be noted that, this is not a forecast table. It is based on the feasibility that the targets defined could be met if decision-makers take the required actions to reach them, hence to commit to activities that promote sustainable future development in Mixteca. The sum of the expected achievable points on each of the future scenarios is shown in a figure at the end of each subsection as a graphical representation (see Figure 29, Figure 30 and Figure 31).

9.2 ICoS goal 1: Securing human existence

Seven criteria out of the eighteen were evaluated under the five rules of the first goal of ICoS; *Securing human existence*. In Table 10 below, an overview of the assessment results is presented; a detailed explanation of how each criterion adapts and applies to each sustainability rule is discussed in the following sections. The last eight columns of the table show the results of the assessment based on the scenario-based process explained in section 5.3.

Table 10. Assessment summary related to ICoS goal 1 "Securing human existence".

Assessment of criteria related to sustainability goal 1: Securing human existence					Cluster 1: "Back to XIX Century"				Cluster 2:"Hope for a better future"			
Sustainability rule	**Criterion**	20	10	5								
		Evaluation reference			**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 5**	**Scenario 4**	**Scenario 6**	**Scenario 7**	**Scenario 8**
Protection of human health	R. Environmental effects on population	Decrease of air pollution particles to meet national standards	Maintaining current levels or minor decrease of air pollution particles	An increase of air pollution particle or lack of monitoring	5	5	5	5	20	20	20	20
Ensuring satisfaction of basic needs	A. Emigration	A substantial reduction of emigration rates	Emigrants who keep a bond in the area	An increase of emigrants with no bond to their hometown	3.33	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	C. Education	Basic and secondary school completion, plus occupational education with soft skills	Partially allow some years (basic education completed but not secondary)	Withholding the basic right to a quality education	1.67	1.67	1.67	1.67	3.33	3.33	3.33	3.33
	E. Basic services access	Every inhabitant has access to reliable basic services	Not every inhabitant has access to all basic services or has partial access to them.	Part of the population has restricted or no access to basic services.	1.67	1.67	1.67	1.67	3.33	3.33	3.33	6.67
Autonomous subsistence based on income from own work	D. Source of income	Remittances decrease and capacity building, jobs, investments increase	Partial dependance on remittances	Strong dependance on remittances	1.67	1.67	3.33	3.33	6.67	6.67	6.67	6.67
	G. Job and earnings	Considerable decrease of population below minimum wage	A light decrease of population earning minimum wage	No change or increase of rate of population below minimum wage	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	A. Emigration	A substantial reduction of emigration rates	Emigrants who keep a bond in the area	An increase of emigrants with no bond to their hometown	3.33	1.67	1.67	1.67	6.67	6.67	6.67	6.67
Just distribution of chances for using natural resources	Q. Climate change	A substantial increase in solar energy share	A meager increase in solar energy share	No contribution to solar energy share	5	5	5	5	20	20	20	20
Reduction of extreme income or wealth inequalities	G. Job and earnings	Considerable decrease of population below minimum wage	A light decrease of population earning minimum wage	No change or increase of rate of population below minimum wage	5	5	5	5	20	20	20	20

Scale used: 5 (red) if the target is highly likely to be missed; 10 (yellow) if the target is anticipated not to improve or only slightly improve; 20 (green) if the target is expected to be accomplished. The letter assigned to the criterion (second column) corresponds to the reference letter on the descriptor / criterion (see Table 8).

9.2.1 Rule 1.1: Protection of human health

The sustainability rule *Protection of human health* has been assessed through the criterion *R. Environmental effects on population*, given that the population in rural Mixteca faces increased exposure to climate change due to its vulnerability. Higher susceptibility to being impacted by the environmental effects and a deeper and slower recovery from adverse impacts of climate change would represent a threat to the population's health and would likely increase inequality. Adaptation to decrease the environmental effects should be integrated as a strategy into the development of the rural area to bring protection to the inhabitants of Mixteca.

The scenarios 1, 2, 3 and 5 in Table 10 show a trend in which human health seems to be threatened by presumably uncontrolled air pollution particles, likely due to a lack of measures or monitoring in Mixteca (see section 7.1.1). In the past years, Mexico has recorded close to 30,000 yearly casualties (International Climate Transparency, 2020) due to high levels of air particles such as PM_{10} , $PM_{2.5}$, O_3. In addition, human health has been affected by heart diseases, lung cancer and chronic respiratory diseases (SEMARNAT, 2020). The future under these scenarios is prone to worsen if Mixteca does not take appropriate measures to monitor and control levels of pollutant air particles to meet at least the national standards. The casualties could substantially increase, as well as the chronic respiratory illnesses related to air pollution. Moreover, the health impacts could widen inequality and slow the recovery in rural Mixteca, where the population could face not only risks and a failure of health protection, but also a seeming economic regression as a consequence. Consequently, this criterion scores poorly, with the lowest points in the defined scale for all four scenarios (color red in Table 10).

In contrast, the four remaining scenarios 4, 6, 7 and 8, could show a trend in which the control of air emissions succeeds, with decreasing levels which diminish the environmental effects on the population. The laws on the *protection of human health* and life seem to be practiced; measures to control the air emissions are enforced, and hazardous anthropogenic activities are monitored and limited. Improvement in health care is part of the public policies so that communities in Mixteca have a healthy environment and protection of human life. Appropriate measures seem to be considered in the future trend of these scenarios in a promising sustainable direction, scoring the highest points for each scenario (color green in Table 10).

9.2.2 Rule 1.2: Ensuring satisfaction of basic needs

Three criteria address the ICoS sustainability rule *Ensuring satisfaction of basic needs*: A. *Emigration, C. Education* and E. *Basic services access*. The criterion A. *Emigration* is addressed further under the ICoS rule: *autonomous subsistence based on income from own work*. In addition, this criterion will also be analyzed under the ICoS goal 2 of *Maintaining society's productive potential* and *preserving society's options for development and action*.

A. Emigration

Emigration is a phenomenon related to a development interaction resulting from inhabitants in the rural area seeking – typically - a dual result: proper livelihood outside their place of origin; and improving living conditions for relatives staying at home through delivery of remittances, thus, seeking to alleviate poverty - addressing *satisfaction of basic needs*. Emigrants look for opportunities to satisfy their basic needs and thus secure their subsistence.

Scenario 1 in Table 10 shows a potential improvement where despite emigrants having left their local communities, they keep a bond with their relatives in the rural area. Emigrants aim to enhance the living standards of their families by sending remittances, and assuring a minimum level of improvement of living conditions, likely in basic care and health, partially paving the path to a possible sustainable future (color yellow in Table 10).

Scenarios 2, 3 and 5 envision a region with a loss of human capital, as Mixteca might likely see an increase of emigrants with no bond, thus, no external means to ensure the satisfaction of basic living or health. Nor does Mixteca seem to contribute to the possibility of securing its future livelihood through its own means. Mixteca seems to face a loss of economic potential, thus a meager future for the community with a lack of perspective. On the other hand, despite having no bond, migrants abroad , are fulfilling the goal of securing their own wellbeing based on their own work, outside their community. This approach is desirable at the individual level but potentially unsustainable for the existence of the whole community. For Mixteca, these scenarios reach the lowest score of the assessment (color red in Table 10).

In contrast, scenarios 4, 6, 7 and 8 show what seems to be a positive perspective for Mixteca. The return of emigrants who left the rural area seeking to improve their living conditions and those of their families, look forward to their return to guarantee a basic standard of living and health care. At the same time, they aspire to assure an autonomous subsistence based on the knowledge and skills acquired during their time abroad. By having the knowledge capital to set the economy in motion, they also make sure their families and community benefit by creating a path to ensure the satisfaction of collective basic needs, and at the same time, potential for autonomous subsistence as a community resulting from their own labor. Thus, these four scenarios have a sustainable potential, scoring the highest outcome in the assessment, (color green in Table 10).

C. Education

Education is a fundamental right that enables an individual to develop their potential to take active, participatory and responsible action in community activities. Education promotes learning opportunities to acquire not only knowledge but skills, values and attitudes. These elements are necessary to make informed decisions that translate into responsible actions for common future wellbeing. Education is the means to empower each individual to secure a future existence and the means to foster competencies that allow further development. Education is a human basic right, hence, a basic need. Furthermore, education is the stepping-stone by which a member of society is enabled to be fully included and recognized as a part of it. Allowing members of rural communities, indigenous and vulnerable groups to access education regardless of gender or background, provides the opportunity to enhance their social development by being involved in decisions that directly affect them.

The scenarios 1, 2, 3 and 5 in Table 10 show that Mixteca might likely be withholding the basic right to quality education, with a prevailing insufficient education - level, organization and quality. This not only hinders the possibility of developing human capital in the area. It also limits the possibility of changing values and the opportunity to develop activities taking into consideration the consequences of sustainable living. People seeking to exert their right to education (where they have the means for it) would possibly tend to move out of the area, leaving it with a lack of potential for improvement. As a result, the lowest grade in the assessment is given for these four scenarios (color red in Table 10).

However, the four remaining scenarios 4, 6, 7 and 8 are inclined to envision an incomplete duration of secondary education, probably with concluded basic education, although this might have some limitations, either poorly structured and / or with insufficient quality. It could nevertheless, foresee a partial improvement, not only in knowledge but in values, future perspective and behaviors. The full potential to change the whole community would however remain underdeveloped. Education should be considered as a long-term goal to break the poverty cycle; the current perspective is still further away from a change of action, and additional efforts are needed to re-direct the path. For this reason, these scenarios cannot be considered sustainable; they have improved compared to the first four (scenarios 1, 2, 3 and 5) but still there is some work to be done, and thus an intermediate assessment is designated (color yellow in Table 10).

E. Basic services access (water, electricity, drainage)

All members of the rural communities should have access to services to guarantee their basic human satisfaction needs: the right to clean water, energy services and drainage. The right to live a dignified and just life ensuring the satisfaction of their basic needs as a sustainability goal should be granted to all, regardless of race, gender or economic condition (further analysis follows in section 9.4.1). Access to water should also consider drinkable water to protect human health. Drainage should also be connected to municipal pipelines to avoid risks of illnesses and ensure proper disposal. Electricity should aim to be generated through renewable sources, mainly solar since the area is suitable to profit from this resource; beyond granting access to electricity, it should be enforced that the supply it is reliable, stable and that it can be used for productive purposes.

The scenarios 1, 2, 3 and 5 in Table 10 seem to prolong the lack of access to basic services for some parts of the population in the rural communities. By neglecting their provision, poverty is inclined to prevail. Without basic services, the welfare of the society is not met, hence, education, employment, health care, social and cultural life are affected, hindering the path to a just and equitable future. Hence, the unsustainable future is reflected in the lowest score of the table (color red in Table 10).

In contrast, the efforts to provide the minimum level of provision with elementary basic services in scenarios 4, 6 and 7, might appear to be an improvement to previous scenarios 1, 2, 3 and 5, but this is insufficient to foresee a sustainable future. Energy services seem to have more availability than water or sanitation due to the solar PV transition. However, the limited availability of energy services does not guarantee reliability and quality, which also play an important role in supply. The future trend in the area foresees a disparity in both supply and reliability. Hence, efforts are still necessary to foresee a successful development in this set of scenarios 4, 6 and 7 (color yellow in Table 10).

The focus of scenario 8 is centered on providing access to reliable basic services for everyone in Mixteca. Ensuring basic services distribution helps address poverty and inequality. The provision of basic services for all in this scenario tends to contribute to the main sustainability condition of ICoS goal 1 *Securing human existence*, consequently this is the only scenario that scores highly in the assessment (color green in Table 10).

9.2.3 Rule 1.3: Autonomous subsistence based on income from own work

Three criteria are analyzed under this ICoS rule: *D. Source of income, G. Job and earnings* and *A. Emigration*. The criterion *D. Source of income* will be further analyzed under each of the other two ICoS goals; G. *Job and earnings* will also be addressed under the rule 1.5 *reduction of extreme income or wealth inequalities* of the same general goal 1 *Securing human existence*; furthermore, it will be discussed under the instrumental rule 4: *fair (inter)national economic framework conditions*. The criterion *A. Emigration* has been discussed above under section 9.2.2, and will also be addressed in sections 9.3.3 and 9.4.1 under the other two ICoS goals.

D. Source of income

The right to work is a fundamental condition to ensure dignity and self-respect as an essential part of being human. The criterion *D. Source of income* related to the sustainability rule *Autonomous subsistence based on income from own work* represents the primary source of income on which one´s own and the family's subsistence depend. Adequate sources of income within the region should be enforced to provide enough income to avoid dependency on third-party funding; basically remittances from relatives working abroad.

The future under scenarios 1 and 2 in Table 10 seems prone to strong dependence on remittances, which exhibits a reflection of the inhabitants' limited possibilities for securing their own livelihood, thus they depend on external economic assistance. As consequence, there are losses of skills, motivation, and effects in family and social life. A lack of a sustainable perspective is a strong trend, which is the reason these two scenarios (1 and 2) score the lowest in the assessment (color red in Table 10).

An improvement to these scenarios is the path under scenarios 3 and 5, which show partial dependence on remittances; this alternative allows possibilities to earn a living through one's own work and to develop oneself through economic and social self-development despite the (remaining) partial external funding) dependence. Additional efforts are needed to see consolidated development and progress in rural Mixteca, thus the assessment is not sustainable yet (color yellow in Table 10).

For the four scenarios, 4, 6, 7 and 8, the amount of remittances decreases, and capacity-building, job opportunities and investments increase; the right to earn a proper living brings additional benefits to the communities beyond economic aspects. *The autonomous subsistence based on income from own work* reinforces social integration in the area; the human resource is recognized and valued, it promotes independence from other external sources, it also brings the opportunity to build a future according to its members' expectations. A better future for generations to come could be foreseen under these four scenarios, and consequently the highest score in the sustainability assessment is observed (color green in Table 10).

G. Job and earnings

The right to work is a fundamental condition to ensure dignity and self-respect as essential parts of being human. Along with this basic right, every member of the community should have means to ensure subsistence by an employment or occupation that provides the necessary income to live a dignified and just life, and the wages (income) should be fair and sufficient to guarantee a proper living. Further livelihood rights such as housing and education depend on or are affected by the provision and quality of work. In addition, working conditions should also be just, safe and healthy. The availability of equal opportunities should also be granted to everyone in a working-age range, regardless of race, gender or social condition and should promote the inclusion of the disabled population. It is highly desirable that disproportionate variances between job-holders' remuneration can be avoided along the productive chain to promote an equitable distribution of wealth, as an essential condition of a sustainable society. The aim to improve the living standards of most of the inhabitants with a focus on the economic growth of the whole community targets poverty alleviation in the rural area.

The four scenarios 1, 2, 3 and 5 in Table 10 foresee a future in which the lack of formal employment would likely anticipate a high percentage of the population in Mixteca earning income below the minimum wage; this situation would be inclined to promote the prevalence and growth of the informal sector. This grey labor market is not only accompanied by a lack of rights for workers -minimum wage, the disparity in working hours, lack of health insurance and social benefits - but also promotes child labor, limits education for future generations, and avoids tax payments. These conditions deprive society of the opportunity to develop a sustainable future that can change social conditions, perpetuating the unequal income gap and the poverty cycle. Thus, the assessment gets the lowest scores (color red in Table 10).

On the other hand, scenarios 4, 6, 7 and 8 foresee a considerable decrease in the population earning below minimum wage, and under those circumstances, an improvement in working conditions, availability of jobs and a better distribution of wealth due to better wages. The aim to promote economic growth in the rural region could also help narrow the income disparities gap between rural and urban communities; further analysis follows in section 9.2.5. The improvement in higher income and better job conditions could also bring positive impacts in education and help strengthen social cohesion among all members of the community. These scenarios also consider the inclusion of different disadvantaged or ethnic groups, stimulating their subsistence based on their own means. Potential economic growth under these scenarios could assist in diminishing poverty, hence they reach a positive sustainable assessment (color green in Table 10).

A. Emigration

One of the principal motivations behind emigration in Mixteca is the search for a job. Emigration involves a circumstance where people look for conditions to develop productive activities to guarantee their subsistence and be able to raise their families freely. A secure livelihood through (self-)employment dignifies a human being; availability of employment opportunities shows a society, where economic, social and political institutions are effective in committing a secure living and guaranteeing autonomous subsistence using revenue from one's own freely-undertaken productive activities. The first motive to leave the region is to pursue a higher educational level. Years later, this would translate into an economic reason to further develop job opportunities. Emigration has played an important role in the social and above all, economic development of Mixteca through temporary, returning and permanent migration. The main aim is to fulfill the sustainable rule of autonomous subsistence and their families' subsistence based on income from their own work.

In scenario 1 in Table 10, inhabitants might not foresee a future where employment opportunities could guarantee subsistence, hence, they find the need to emigrate; nevertheless, they keep a bond to their families or communities of origin in the expectation to assist those left behind through remittance deliveries, which might help alleviate lack of employment or provide future economic opportunities to generate productive activities (color yellow in Table 10).

Scenarios 2, 3 and 5 are highly likely to foresee a lack of (self-)employment opportunities, and then subsistence is jeopardized. As a consequence, inhabitants have no choice but to emigrate, leaving the area with meager prospects for the future, since their departure would be permanent with no bond to their area of origin (color red in Table 10).

By contrast, scenarios 4, 6, 7 and 8 could anticipate returning emigrants and a reduction of emigration rates. Those who kept a bond with their communities could envision a future where the skills gained and savings accrued during their time abroad could create employment opportunities to actively contribute to their subsistence as well as the communities' economic growth. The falling emigration rates in the region are likely to translate into positive socio-economic perspectives in the area, thus the highest assessment results are exhibited in green color in Table 10.

9.2.4 Rule 1.4: Just distribution of access to natural resources

Managing, conserving and responsibly using natural resources in Mixteca would assist in the national effort to reduce the impact of climate change. Hence, the criterion *Q.* C*limate Change* considers that the population uses natural resources in a just manner and does not jeopardize the opportunities for future generations to use them, addressing the ICoS rule *Just distribution of access to natural resources*. Climate change may certainly increase inequalities, raising future concerns about boosting existing social disparities in prejudice of the inhabitants of the rural region.

The scenarios 1, 2, 3 and 5 in Table 10 may potentially display signs of showing a failure to address climate change issues due to a lack of contribution to solar energy share. The continuous use of fossil fuels is likely to be a possible reason for environmental degradation contributing to climate change. As a consequence, a lack of control in atmospheric emissions would likely produce environmental degradation and would deprive a future generation of the use of natural resources. A failure to take appropriate measures to mitigate the impacts of climate change might produce scarcity of water for productive activities, including; the rain-fed agriculture would result in lower production; atypical rains would affect the scarce crops; an increase in more resistant pests would affect meager agriculture in the area; lower river flows. These effects mean that the consequences of present decisions would be inherited by future generations, restricting their right to use and benefit from natural resources - quantity and quality - in the future. The lowest scores in the assessment are assigned to these scenarios, as shown in red color in Table 10.

On the contrary, scenarios 4, 6, 7 and 8 seem to contribute to the generation share of solar PV energy in Mixteca; this measure assists in addressing the future consequences of climate change. Mixteca is likely to succeed in taking part of the solar PV energy generation share, contributing to lower consumption of fossil fuels; also contributing to the national decrease of GHG emissions. These measures could help alleviate the possible negative impacts in the future, providing a better opportunity for coming generations to benefit from natural resources. These scenarios seem to enforce the sustainability goals and climate change laws as a responsible way to a promising future, revealing an encouraging green perspective for the future, as shown in the highest score of the assessment (color green in Table 10).

9.2.5 Rule 1.5: Reduction of extreme income or wealth inequalities

A job is a widespread occupation through which someone earns a living, involving physical and mental tasks in the pursuit of economic prosperity. A job could be potentially harmful if the working schedule is too long, the conditions under which the job is performed are not adequate or the income received is not sufficient to cover minimum needs. Income might be a route to achieve some accumulation of wealth; it also serves to highlight an area of inequality that is structural to modern society. A clear impact of unequal distribution of wealth is the persistent poverty in Mixteca over many decades. The region has been locked into a dependent relation of evident inequality with few options to move out from the traditional economy that determines how wealth is created and distributed. This might suggest that tackling poverty may not reduce wealth inequality in Mixteca, and the focus should be a suitable income that promotes meeting general wellbeing, not just a minimum level of basic needs. The target of no-one living below minimum wage, pragmatically means that there must be a substantial reduction in the current 75% of the population who cannot meet their basic needs due to below minimum earnings in Mixteca (see section 3.5).

The scenarios 1, 2, 3 and 5 in Table 10 reflect the continuation of the current income conditions in the rural region, showing an increase in the rate of the population below minimum wage. Increased wealth gaps will persist, the inability of the social institutions to provide sustainable livelihood opportunities translates into precarious jobs and unlivable salaries. Economic insecurity and unequal opportunities for jobs will be a challenge in the future of this cluster; hence the low scores in the assessment reflect future unsustainability due to failing to meet the targets appear in the red color in Table 10.

In contrast, the scenarios 4, 6, 7 and 8 seem to connect the expectations with a practice in which a minimum wage could be designed as a living wage. A significant decrease in inequality might promote not only economic development but also human rights in an attempt to get out of the poverty trap. The future under this cluster could be a desired path for local society, where the creation of fair jobs or income opportunities could be seen as high-value work and no longer low-skilled, hence good assessment results are assigned, shown in green color in Table 10.

9.2.6 Summary of ICoS goal 1 assessment

Figure 29 depicts a graphical summary of the sustainability assessment of the eight scenarios for ICoS goal 1 *Securing human existence*. The future situation in scenarios 1, 2, 3 and 5 could highly jeopardize human wellbeing, the environment and existence. These four scenarios are represented in Cluster 1 “Back to XIX Century” (see section 8.3). Given the total equal scores for scenarios 3 and 5, these scenarios overlap, hence it seems only scenario 5 is displayed. The same situation obtains regarding equal total assessment points for scenarios 4, 6 and 7; these three scenarios overlap, and as a result, the chart seems to present only 2 scenarios: 7 and 8.

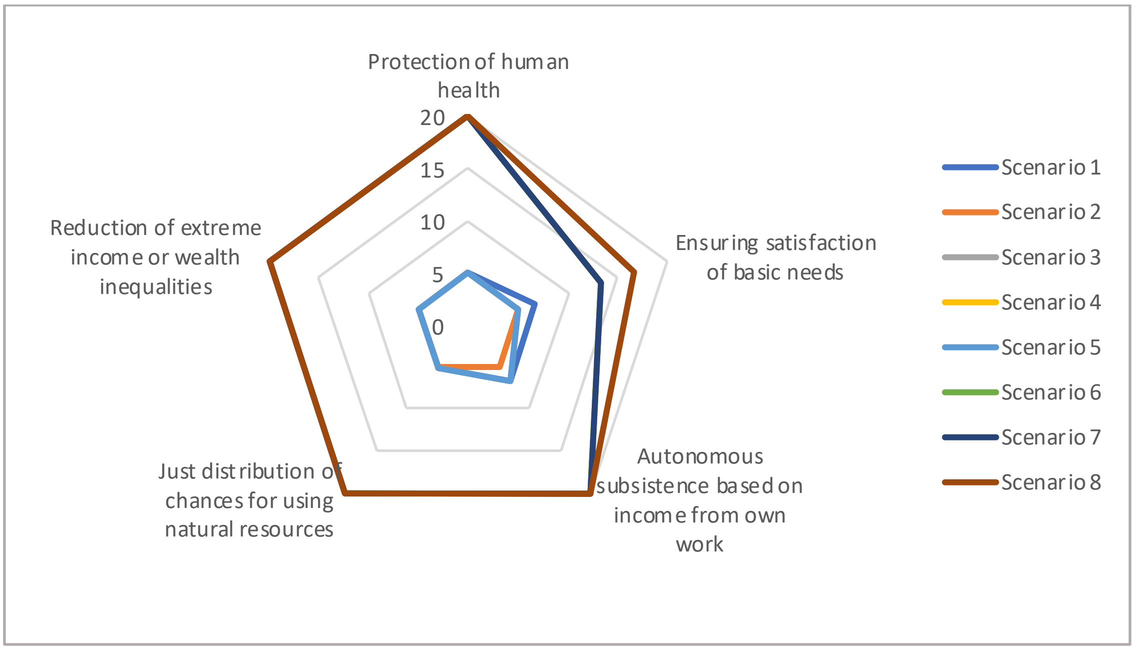


Figure 29. Graphical representation of the assessment of ICoS goal 1: Securing human existence.

From the illustration, we observe scenarios 1, 2, 3 and 5 (inner pentagon cluster in the center of the graph) where low scores on the assessment represent smaller figures than the other four scenarios 4, 6, 7 and 8 which are represented in the bigger pentagon clusters. The two distant clusters of pentagons show the extent of the gap between the two clusters of scenarios.

In a contrasting representation, scenarios 4, 6, 7 and 8, whose path "Hope for a better future" (see section 8.4) was presented in Cluster 2, seem to envision a promising future. Scenario 8 stands out slightly from the rest of the scenarios in the cluster mainly due to improvement in criterion *E. Basic services access* where the future under this scenario foresees that population will have access to all services. The only criterion that might lag behind a "fully attained" sustainable future in scenario 8 is *C. Education.* However, this single criterion assessment does not downgrade scenario 8 from its promising sustainable outlook.

Compared to scenarios 1, 2, 3 and 5 (presented in Cluster 1), scenarios 4, 6, 7 and 8 show a positive significant integration of environmental, social, political, technological and economic aspects to *protect human health*, *ensure satisfaction of basic needs* while caring for a *just distribution of access to natural resources*, as well as to providing security for the population through autonomous subsistence in what could be a *reduction of extreme income or wealth inequalities.*

The criteria assessed in this section meet the most fundamental condition of sustainability, related to the subsistence and *protection of human health* (rule 1.1) and their natural environment. People emigrating from Mixteca in an attempt to guarantee and protect their livelihood, education and access to basic services look forward to securing their existence in the rural area or outside of it, basically, *ensuring satisfaction of basic needs* (rule 1.2). The availability of jobs and the possibility to guarantee earnings through employment opportunities without the need to emigrate, are related to the search for an *autonomous subsistence based on income from own work* (rule 1.3), which would secure the population's existence in Mixteca. The opportunity to plan for a sustainable future where wages and earnings could be fair would avoid wealth gaps and high disparities, providing future development in the rural area. Hence, *reduction of extreme income or wealth inequalities* (rule 1.5). Climate change impacts due to fossil fuel-use are accelerating the need for an energy transition, hence the pressure to increase the share of clean and renewable sources, in an attempt to a *just distribution of access to natural resources* (rule 1.4). The approach that could become an effective energy system transformation to ensure the continuation of human existence would allow the environment to recover adequately from the depletion of resources caused by their exhaustive use.

9.3 ICoS goal 2: Maintaining society´s productive potential

Eight criteria were addressed under three rules of the second goal of ICoS "Maintaining society's productive potential". Two rules of this goal were not addressed: *Sustainable use of non-renewable resources (rule 2.2)*, and *Avoiding technical risks with potentially catastrophic impacts (rule 2.4)*, since they do not apply to our case (see section 7.2; see Table 5 in section 5.1 for the complete list of rules).

Table 11 summarizes the criteria which were analyzed under each sustainability rule addressing the second ICoS goal, and presents an overview of the assessment results. A detailed explanation is provided in the following sub-sections. The last eight columns show the results of the assessment based on the *Scenario-based sustainability assessment* explained in chapter 0.

Table 11. Assessment summary related to ICoS goal 2 "Maintaining society´s productive potential".

Assessment of criteria related to sustainability goal 2: Maintaining society´s productive potentials					**Cluster 1: "Back to XIX Century"**				**Cluster 2:"Hope for a better future"**			
		20	10	5								
Sustainability rule	**Criterion**	**Evaluation reference**			**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 5**	**Scenario 4**	**Scenario 6**	**Scenario 7**	**Scenario 8**
Sustainable use of renewable resources	J. Investment in RE research	Significant increase of investments in energy research	A meager increase of investments in energy research	Reduction or stagnations of investment in energy research	2.5	2.5	2.5	2.5	10	10	10	10
	N. Added Value	A sustancial added value generated from solar sources in the area	A minor added value generated from solar sources in the area	A decrease in added value generated from solar sources in the area	2.5	2.5	2.5	2.5	10	10	10	10
Sustainable use of the environment as a sink for waste and emissions	Q. Climate change	A substantial increase in solar energy share	A meager increase in solar energy share	No contribution to solar energy share	2.5	2.5	2.5	2.5	10	10	10	10
	R. Environmental effects on population	Decrease of air pollution particles to meet national standards	Maintaining current levels or minor decrease of air pollution particles	An increase of air pollution particle or lack of monitoring	2.5	2.5	2.5	2.5	10	10	10	10
Sustainable development of man-made, human and knowledge capital	A. Emigration	A susbstantial reduction of emigration rates	Emigrants who keep a bond in the area	An increase of emigrants with no bond to their hometown	2	1	1	1	4	4	4	4
	C. Education	Basic and secondary school completion, plus occupational education with soft skills	Allowing partially some years (from 5 to 9) of education	Withholding the basic right to a quality education	1	1	1	1	2	2	2	2
	I. Policies f/RE	A substantial increase in solar energy generation	Slight increase of solar energy generation	Decrease of solar energy generation	1	1	1	1	4	4	4	4
	P. Legal System	Significant reduction of corruption levels	Minor reduction of corruption levels	No reduction or increased levels of corruption	1	1	1	1	4	4	4	4
	J. Investment in RE research	Significant increase of investments in energy research	A meager increase of investments in energy research	Reduction or stagnations of investment in energy research	1	1	1	1	4	4	4	4

Scale used: 5 (red) if the target is highly likely to be missed; 10 (yellow) if the target is anticipated not to improve or slightly improve; 20 (green) if the target is expected to be accomplished.
The letter assigned to the criterion (second column) corresponds to the reference letter on the descriptor/criterion (see Table 8).

9.3.1 Rule 2.1: Sustainable use of renewable resources

Two criteria are analyzed under this rule: *J. Investments in energy research* will be addressed under two rules within this ICoS goal: *Sustainable use of renewable resources* and *Sustainable development of human-made, human and knowledge capital*. Along with the criterion *N. Added value creation from the renewable energy sector*, this criterion will also be assessed as framework conditions under the instrumental rules in section 9.7.

J. Investments in energy research

A society can develop, grow and alleviate poverty as long as there is capacity-building, for which investment is required. Energy investment has a core role within any country's productive system, on which dependent areas such as transportation, health care, banking, manufacturing and more rely. Hence, it is imperative that a major shift from a fossil fuels-based system to a renewable solution takes place. Investment in renewable energy research helps develop a sustainable system by creating jobs, building skills, strengthening economic benefits and increasing the local capacity to benefit. In Mixteca, the investment in energy research is mainly addressed to the solar energy supply. The energy research investments also relate to the rule of *Sustainable development of human-made, human and knowledge capital* (see section 9.3.3).

The future state of the criteria in scenarios 1, 2, 3 and 5, presented in Table 11, is likely to show a low investment or none in energy research, hence, the generation potential is neglected, jeopardizing a transition to solar PV source in the region. If the investments are made solely on a one-time basis or are occasional, the future impacts could not be sustained. Thus, the sustainable targets are likely to be missed, consequently the low scores on the assessment (color red in Table 11).

In contrast, under the set of scenarios 4, 6, 7 and 8, a high level of investments in energy research is foreseeable, paving the path to what seems a plausible sustainable transition to solar PV energy. A continuous investment strategy seems to be adopted rather than intermittent or occasional investments. Moreover, these investments consider that research is promoted, and adequate infrastructures and budget are properly allocated. This set of scenarios show a sustainable perspective, hence the targets are expected to be accomplished, hence the high scores in the assessment (color green in Table 11).

N. Added Value creation from the renewable energy sector

The economic performance of projects from renewable sources is required to an extent to allow society to work and be maintained through the production of goods and services, capacity-building and jobs. These can serve their own needs or incorporate them into (inter)national trade processes. Knowledge is also an added value creation that can be translated into policy goals to support renewable energy systems creation, thus, the ICoS rule *Sustainable use of renewable resources* fits into this call. Experience and skills are acquired through jobs that stimulate different industries in the local or national economy.

The state of Puebla is the 11^{th} state contributor to the country's GDP - out of 32 - with 3.2% of the GDP (INEGI, 2020c). Mixteca represents one-third of the state territory whose contribution has remained untapped. Mixteca could increase the economic share provision of the state by harvesting solar energy and thus play a (small) role in the GDP of the state.

The scenarios 1, 2, 3 and 5 exhibited in Table 11 could foresee a decrease in the added value rate generated from solar PV systems. This situation will discourage additional activities related to solar energy generation. It would be likely that the population could be reluctant to acquire skills, education and investment in this sector. Another probable alternative is that the benefits obtained from the creation of added value do not remain in the area, as additional income could be taken away by outsider investors benefiting from the local area. Scores on the assessment are low graded (color red in Table 11).

Contrasting with the previous cluster, scenarios 4, 6, 7 and 8 could envision that the added value generated from solar PV energy systems in the area has increased significantly and could be used to promote additional activities to benefit the rural population, i.e., increase education level, promotion of new projects, acquisition of skills, new investments, new jobs in the area. These activities could enhance economic activities in Mixteca, thus, progress and a resilient development could be envisioned. Consequently, a sustainable future can be depicted, and the assessment scores get the high evaluation (color green in Table 11).

9.3.2 Rule 2.3: Sustainable use of the environment as a sink for waste and emissions

Criteria *Q. Climate change* and *R. Environmental effects on population* were previously addressed in sections 9.2.4 and 9.2.1 respectively, and both will also be addressed as framework conditions in the instrumental rules in section 9.7, since both criteria are basic conditions for sustainability.

Q. Climate change

The criterion *Q. Climate change* can also be evaluated through the ICoS rule *Sustainable use of the environment as a sink for waste and emissions* of the second sustainability goal. The responsibility to use and dispose of the materials or substances resulting from human activities into the environment should be led by present generations to avoid irreversible damage in the future. Special attention should be given to non-biodegradable materials / substances or those which are biodegradable only over long periods of time, that are widely distributed in the environment. It is highly desirable to reduce as much as possible all human-material releases whose effects have not been anticipated and where a regeneration capacity in the environment has not been determined.

It is highly desirable to substantially increase the renewable energy share (committed national increase of 50% by year 2050, see section 7.4) to be able to effectively contribute to the goal of reducing the impact of climate change; an implicit outcome of this measure will be the decrease of GHG emissions, since fossil fuels use and production will be limited.

Scenarios 1, 2, 3 and 5 exhibited in Table 11 show a future which is not likely to contribute to solar energy production share, favoring fossil fuels over renewable energy. As a consequence, this would clearly not help mitigate GHG emissions, thus the assimilation capacity of the environment would be exceeded, with consequential damage and irreversible alterations in the ecosystems, such as the increase in more resistant pests that affect crops, less production of native fruits and vegetables, a decrease in the breeding of livestock species due to drought, increase in chronic illnesses in the population due to air pollution, all jeopardizing a future in the local area. These scenarios will not fulfill the target and score poorly in the sustainability assessment (color red in Table 11).

Contrasting with previous scenarios (1, 2, 3 and 5), scenarios 4, 6, 7 and 8 will set the solar PV energy transition in motion, and their support would foresee the progression of a larger share of clean energy that could contribute to the national efforts to increase the total share of renewable energy. The larger the magnitude, the greater the effort that could assist to reduce GHG emissions, and enable reliable environmental protection for future generations. For this reason, the assessment grades positively with the highest points (color green in Table 11).

R. Environmental effects on population

The criterion *R. Environmental effects on population* can also be assessed under the second ICoS goal under the rule of *Sustainable use of the environment as a sink for waste and emissions*, given the pernicious effects of anthropogenic activities in the environment. As previously defined (see section 7.4), substance releases into the environment should be decreased or avoided, to avoid not only effects on the ecosystems but also on human health. The vulnerable population in the area could be the first group impacted, highlighting the lacks and needs.

The scenarios 1, 2, 3 and 5 presented in Table 11 show signs of insufficient monitoring of inadequate prevention measures, which could plausibly foresee the rise of air emissions particles (PM and O3 as defined in section 7.4) polluting the environment, thus a high effect on the population. The assimilation capacity of the environment seems to be exceeded, so an unlikely regeneration would allow deterioration of the ecosystems in the area with every form of life affected - human, flora and fauna. These four scenarios manifest a high possibility of devastating consequences for the rural communities, given the premise that the assimilation capacity of the environment would be exceeded. Consequently, an unsustainable future is foreseen, missing the targets and scoring the lowest in the assessment (color red in Table 11).

In contrast, scenarios 4, 6, 7 and 8 show a high probability that the emissions system could be controlled to the extent that air emissions particle (pollutants) levels could be contained and reduced. The development could take place in the area with no major threat to the environment, for the benefit of future generations. It is also noteworthy that, despite local efforts in the rural area, these will not prevent the deterioration of the overall environment (i.e., the rest of the state or country). Coordinated efforts are required at all levels - local and national - to foresee major benefits to the environment and population. Nevertheless, the local contribution of Mixteca could provide a path to sustainability, therefore, a high note is given in the assessment (color green in Table 11).

9.3.3 Rule 2.5: Sustainable development of human-made, human and knowledge capital

Five criteria will be addressed under this rule: *A. Emigration, C. Education, I. Governmental policies for integrated energy system, P. Legal System* and *J. Investments in energy research.*

A. Emigration

The criterion *A. Emigration* can also be addressed under the rule of *Sustainable development of human-made, human and knowledge capital* in the second sustainability goal. An important precept of any society is the ability to transcend to generations to come. The creation of wealth and economic development in Mixteca lies in the ability to produce goods and services to promote autonomous living in the communities, as well as to promote an exchange with other communities. The creation and dissemination of knowledge are also part of the development of human capital. The improvement of education is also tied to the acquisition of, or improvement in, skills and knowledge (human capital).

In scenario 1 in Table 11, it is estimated that the emigration flow will continue but emigrants living mostly outside of the country (USA) will keep a bond with their communities of origin, either by enhancing knowledge capital - disseminating traditions - or by providing physical capital -remittances - to their communities of origin. The skills and training received by emigrants during their stay abroad also serve as personal development; in the future, if emigrants decide to return to their communities, these skills could be useful as productive potential to benefit the whole community. While this first scenario is still limited to personal development, it paves the path to an incipient development. Hence, for the collective wellbeing the outcome is not completely sustained; it is an improvement and a step into a sustainable future, hence the assessment scores in the middle note (color yellow in Table 11).

One step back, scenarios 2, 3 and 5 in the same Table 11 foresee a region with a loss of human capital, emigration rates increase with no bond with the place of origin. Thus, Mixteca conceives a loss of economic potential which features a meager future for the community and a lack of outlook. Considering that emigrants look for better education and are better prepared than the rest of the community, a knowledge deficit restricts social participation in the local communities too. The lowest score of the assessment is assigned to these scenarios (color red in Table 11).

On the contrary, the four scenarios 4, 6, 7 and 8 foresee the return of emigrants, now skilled workers, to rural Mixteca. It could also mean they come back with their own capital to push economic activity and create job opportunities in the region. In addition, knowledge capital acquired abroad could set the economy in motion, not only to generate revenue but to promote education, social development and the wellbeing of the communities. Therefore, a positive and high assessment notes are assigned to this set of scenarios (color green in Table 11).

C. Education

In its relation to the ICoS rule *Sustainable development of human-made, human and knowledge capital*, criterion *C. Education* is a basic condition a member of a society should hold by having the skills, competences and knowledge to enact changes in economic, ecological and social behavior. It also enables them to participate in the decision-making process of the community, and enables the creation of knowledge to foster both individual and community development, so that a society can keep its productive potential (human and knowledge capital); e.g., robust institutions created in the local area could produce information databases, regulations and traditions that can lead to a solid future. Education also brings the necessary skills to create value in society through investment that would translate into capital formation and assets acquisition, i.e., solar modules (physical capital). The capability of the inhabitants, along with the willingness to engage in producing physical, human or knowledge capital drive the society to change, and with suitable awareness and efforts, could be driven along a sustainable path. In this way, education serves the purpose of maintaining society's productivity. The acquisition of knowledge capital through education enhances values and future outlook in the area. It can change behaviors and alleviate poverty by providing economic development in Mixteca.

Scenarios 1, 2, 3 and 5 exhibited in Table 11 are likely withholding education in the region; they highly likely show stagnation in education, either by the number of school years, quality or both. This condition prevents adequate human and knowledge capital creation in the area. Economic performance seems to be limited as a consequence. Those members of the communities aiming to improve would need to emigrate from the area to cope with the human and knowledge capital creation to the detriment of the rural communities. Thus, the scores on the assessment are the lowest, marked in red in Table 11.

Scenarios 4, 6, 7 and 8 are also inclined to limited education level and quality; basic education might be completed but not secondary education (less than 9 years schooling). It is however recognized as an important human and knowledge investment needed for the development of a society. A partial contribution to the improvement and creation of skills and knowledge capital can be foreseen, although additional efforts are still required to make significant growth. Consequently, the middle scores (color yellow in Table 11), are assigned to these scenarios in the sustainability assessment.

I. Governmental policies for integrated energy system

Energy policies uphold knowledge capital that provides the framework that can influence a sustainable transition of an energy system. Local community institutions relate directly to practices responding to, supporting or impeding policies of a transformation. These policies are the result of the knowledge capital that would allow a society to promote a sustainable change to encourage environmental renewable energy generation along with a socio-technical change. Policies and their accompanying measures have the facility to address inclusion and gender equality, reduce air emissions, create economic incentives for a shift towards a renewable system, and engage inhabitants into an operative and dynamic organization. The ability and possibility to produce goods, services and knowledge for the society's own needs as well as a trading process between other communities within Mixteca or regions outside of it, contribute to the growth and development of the local area. Within the framework of social responsibility and environmental care, the sustainable potential becomes linked to the benefit of future generations.

The scenarios 1, 2, 3 and 5 presented in Table 11, exhibit a future where policies still support the promotion of fossil fuels, consequently decreasing or not even generating solar energy; this situation could be a strongly enduring reality in Mixteca. Uncertainties over how policies restrict solar or other renewable energy generation might not be aligned to future energy needs, and would not promote a sustainable future, thus endangering the coming generations' development. Clear signals and direction from policymakers are essential, but are missing in this set of scenarios. A lack of or restricted creation or promotion of human and knowledge capital through an obsolete fossil-fuel energy system would prevail, therefore, the lowest points are granted in the assessment (color red in Table 11).

Under scenarios 4, 6, 7 and 8, the creation of knowledge capital seems to effectively link policies that reflect a future sustainable reality through the promotion of solar energy generation, discerning a substantial increase in its production. Renewable energy policies (knowledge capital) created under this premise could contribute to solar energy generation for sustainable development in Mixteca. Solid human and knowledge capital can help shape effective policies for a local shift into a solar PV system. In Mixteca, solar energy promotion policies could enhance education in related areas where the population could directly benefit from acquiring skills useful for improvement and direct application in the area. Therefore, policies play a crucial role in determining how a solar energy system can be adapted and scaled up in Mixteca; this set of scenarios seem to attain its target, on this account, positive assessment numbers are marked (color green in Table 11).

P. Legal System

Effective practice of the legal system in Mixteca could guarantee the rule of law that endorses the development of the area. Consequently, the ICoS rule *Sustainable development of man-made, human and knowledge capital* can be useful to assess this criterion. The pursuit of the rule of law in the local instances in Mixteca would ensure that the knowledge capital and human capital are available and granted to all members of the community. This would allow each member of the community the opportunity to have access to basic services, the promotion of social development, environmental protection, sustainable management of natural resources and the right to contribute to the creation of human and knowledge capital in Mixteca. Then, the promotion of economic development in the area could be foreseen, with fair outcomes and an inclusive society.

Under scenarios 1, 2, 3 and 5 presented in Table 11, Mixteca could anticipate the aggravation of the legal system; increased levels of corruption (or no reduction in the best case), would inhibit social justice and hinder a future with poor economic development due to a knowledge creation deficit. The high level of corruption is likely to undermine the region's development, promoting inequity and poverty. Therefore, the unsustainable perspectives score the lowest in the assessment (color red in Table 11).

By contrast, scenarios 4, 6, 7 and 8 could visualize a future in which society in Mixteca is committed to participation, which has matured, confronted corruption and diminished it to a small extent. The legal system could reach an effective level of practice where members of the rural area could benefit from efficient knowledge that applies to the complex social system and reach justice. The objective of curbing corruption in the area could succeed towards progress and sustainability. To that end, positive assessment grading is provided for these scenarios (color green in Table 11).

J. Investments in energy research

Access to energy has a seemingly evident connection to energy infrastructure. Nevertheless, energy research is not only related to deployment or development of new technology or infrastructure, but also to the generation of knowledge through education, building skills, training, preparing future generations to welcome new ideas, open mindsets, and change paradigms. In this way the productive potential can be generated through self-sustained economic opportunities that can also promote social development. Therefore, criterion *J. Investments in energy research* also relates to the rule *Sustainable development of human-made, human and knowledge capital*.

In the scenarios 1, 2, 3 and 5, shown in Table 11, Mixteca seems to envision a future where society is still reluctant to make the switch to a transformative change of energy system with low levels of investments in solar PV energy research. The current status quo shows signs of persisting in future decades, with the risk of not meeting the needs of future inhabitants. Gross domestic expenditure in energy research could remain limited and well below the national and worldwide standard. For this reason, the lowest scores are assigned in the assessment (color red in Table 11).

In contrast, scenarios 4, 6, 7 and 8 might reflect a reshaping of the energy system into renewable sources, profiting above all from solar generation. The significant increase in investment allowing a percentage of the GDP in energy research and technology to support solar sources and the transition at the policy level, go along with the interest of the government in more sustainable orientation and integrating the social requirements for energy, qualifying people to keep the society running. Thus, a favorable score is shown in the assessment (color green in Table 11).

9.3.4 Summary of ICoS goal 2 assessment

Figure 30 shows a graphical summary of the sustainability assessment for ICoS goal 2, *Maintaining society´s productive potentials*. The Figure shows two distinct triangles, related to the two distinct clusters (see section 8.2) in which the eight scenarios have been arranged (see Figure 28 in section 8.2). The four scenarios of Cluster 2 (scenarios 4, 6, 7 and 8), shown in the biggest triangle, are superimposed and appear to be only one due to the fact that the assessment results are the same. A similar situation is observed in Cluster 1, but with a slight variation in scenario 1 pertaining to the rule *sustainable development of human-made, human, and knowledge capital*. However, the minor difference does not have a significant impact on the outcome, so it can be disregarded. As a result, two major trends are evident reflecting the assessment's main outcome; one sustainable path comprised by the scenarios 4, 6, 7 and 8 (highest scores depicted in the biggest triangle) and the other not sustainable future conformed by the scenarios 1, 2, 3 and 5 (lowest scores presented in the smallest triangle). The sustainable path is evenly distributed among the three ICoS goals and appears to be well balanced. Under this sustainable outlook, criterion *C. Education* is slightly behind its sustainability goal under the rule *sustainable development of human-made, human, and knowledge capital* without jeopardizing the Cluster 2 promising sustainable future.

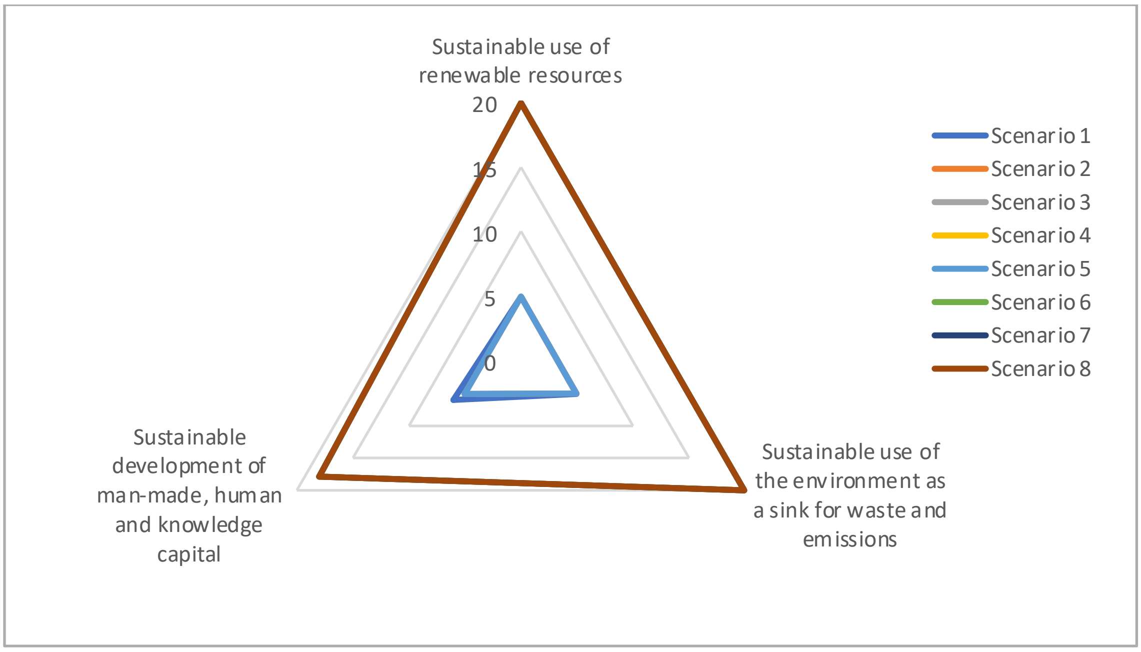


Figure 30. Graphical representation of the assessment of ICoS goal 2: Maintaining society's productive potential.

Thus, the major trend seems to have a minimal impact. In essence, all four scenarios of Cluster 1 (scenarios 1, 2, 3 and 5) show an unsustainable perspective for Mixteca, whereas the four scenarios related to Cluster 2 (scenarios 4, 6, 7 and 8) show a sustainable future for the second goal of sustainability *Maintaining society´s productive potential*. Since basically the two sets of four scenarios have the same scores, no particular scenario stands out among the rest.

What the assessment of these criteria means is that managing the transformative change of energy starts at the policy level, going through the social institutions to open up opportunities for future prospects. The investment in changes at a system level improves not only the innovation of the technology but also the direction of the innovation for transforming the traditional system towards sustainable energy solutions. The physical, human and knowledge capital necessary to guarantee that the productive potential of the society in Mixteca can be sustained, should focus on integration into the economic process, within the boundaries of sustainability objectives. Therefore, investments (technological-based or organizational, institutional, policy-based) with environmental considerations could turn into relevant alternatives with less impact on the social-ecological system from an economic perspective.

The criteria assessed refer to the sustainability postulate related to the availability of comparable opportunities for future generations to meet their needs, which do not necessarily refer to the same opportunities as today's generations. It relates to the productive capacity of the society to be preserved over time. Therefore, productive capacity is related to J. *Investments in energy research* and the N. *Added value* generated from the *sustainable use of renewable resources* (rule 2.1); the high concentration of air emissions of PM and O_3 affecting *Q. Climate change* could decrease if a bigger share of renewable energy was used to diminish the *R. Environmental effects on population* in the attempt to reach a *Sustainable use of the environment as a sink for waste and emissions* (rule 2.3). Lower emigration rates, higher and quality education within an appropriate legal system promoting the rule of law and enhancing governmental policies for an integrated energy system, could promote the *sustainable development of human-made, human and knowledge capital* (rule 2.5) in the region.

9.4 ICoS goal 3: Preserving society´s options for development and action

Nine criteria are addressed under the rules of the third and last goal of ICoS, *Preserving society´s options for development and action.* Three criteria: *A. Emigration*, *C. Education* and *D. Source of income* had already been assessed under the previous goals 1 and 2. Six criteria will also be addressed as part of the instrumental rules (section 9.7): *S. Women's empowerment*; *F. Population acceptance of renewable energy plans and participation*; *M. Cooperation between government, private investors, NGOs*; *T. Community organization*; *B. Ethnic identification*; *D. Source of income*. These nine criteria also belong to the framework rules, thus, these are significant criteria for the fulfillment of a sustainable future. They are also a requirement for the society's future consolidation. Table 12 below summarizes the criteria analyzed under each sustainability rule addressing the third ICoS goal, and presents the overview of the sustainability assessment results. A detailed explanation about the assessment of these nine criteria follows in the next sub-sections 9.4.1 to 9.4.5. As explained in Table 10 and Table 11, the last eight columns show the results of the assessment based on the scenario-based process explained in section 5.3.

Table 12. Assessment summary related to ICoS goal 3: "Preserving society's options for development and action".

Assessment of criteria related to sustainability goal 3: Preserving society´s options for development and action					**Cluster 1: "Back to XIX Century"**				**Cluster 2: "Hope for a better future"**			
Sustainability rule	**Criterion**	20	10	5	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 5**	**Scenario 4**	**Scenario 6**	**Scenario 7**	**Scenario 8**
		Evaluation reference										
Equal access for all people to information, education, occupation	A. Emigration	A susbstantial reduction of emigration rates	Emigrants who keep a bond in the area	An increase of emigrants with no bond to their hometown	3.33	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	C. Education	Basic and secondary school completion, plus occupational education with soft skills	Allowing partially some years (from 5 to 9) of education	Withholding the basic right to a quality education	1.67	1.67	1.67	1.67	3.33	3.33	3.33	3.33
	S. Women's empowerment	Substantially increase women's employment rate	Slight increase of women´s employment rates	Lack of promotion and decrease of women's employment rates	1.67	1.67	1.67	3.33	6.67	3.33	3.33	6.67
Participation in societal decision-making processes	F. Population acceptance of RE	Existence of at least one steady local solar PV project per municipality	The scarce or sporadic existence of local solar energy projects	The lack of local solar energy projects	3.33	3.33	3.33	3.33	6.67	3.33	6.67	6.67
	M. Cooperation between government, private investors, NGOs	Substantial increase of loans to promote productive activities	Minor or scarce loans to promote productive activities	Lack of loans to promote productive activities	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	T. Community organization	Existence of at least one steady community project aimed at the collective productive benefit	The scarce or sporadic existence of community projects aimed at the collective productive benefit	A decrease or no promotion of community projects aimed at the collective productive benefit	3.33	3.33	3.33	3.33	3.33	3.33	3.33	6.67
Conservation of cultural heritage and cultural diversity	B. Ethnic identification	Increase of the quantity of indigenous language speakers	Maintaining the same quantity of indigenous language speakers or minor increase	A decrease of the quantity of indigenous language speakers	20	10	10	10	20	20	20	20
Conservation of the cultural function of nature	B. Ethnic identification	An increase of protection of areas, flora and fauna awareness	A stagnation in protected areas, light awareness on flora and fauna	A decrease of protected areas, as well as in flora & fauna protection	20	10	10	10	20	20	20	20
Conservation of social resources (tolerance, solidarity...)	D. Source of income	Remittances decrease and capacity building, jobs, investments increase	Partial dependance on remittances	Strong dependance on remittances	5	5	10	10	20	20	20	20

Scale used: 5 (red) if the target is highly likely to be missed; 10 (yellow) if the target is anticipated not to improve or slightly improve; 20 (green) if the target is expected to be accomplished. The letter assigned to the criterion (second column) corresponds to the reference letter on the descriptor/criterion (see Table 8).

9.4.1 Rule 3.1: Equal access for all people to information, education, occupation

Following three criteria will be addressed under this rule: *A. Emigration, C. Education* and *S. Women's empowerment.*

A. Emigration

In addition to the first two ICoS goals, the criterion *A. Emigration* can also be analyzed under the third sustainability goal, whose rule *Equal access for all people to information, education, occupation* suits the purpose. To prevent social exclusion, this rule intends to ensure equal access for all members of the community to the social benefits that allow them to be recognized as an individual holder of rights, boosting their capabilities and opportunities regardless of gender, race or vulnerability degree. The indicator *emigration rate* should aim to decrease in order to bring Mixteca the social development the region aspires to.

Scenario 1 in Table 12 depicts a future in which emigrants have left Mixteca due to the scarce alternatives to perform an occupation or employment suitable to their life plans. These emigrants are likely to keep a bond to provide remittances to help their relatives to take the opportunities to access education, occupation, political rights and social inclusion, in an attempt to bring a sense of equality to the disadvantaged part of the population. Even though the emigration rates have not decreased significantly, the bond kept by emigrants provides some sustainable perspective, hence an intermediate degree is shown with color yellow in the assessment in Table 12.

In scenarios 2, 3 and 5 of Table 12, migrants have left the rural region looking for opportunities to access education, jobs or to improve their social position. It could be that people have been subject to discrimination due to gender, or ethnic or cultural differences, hence they have faced the need to emigrate in search of equal access to opportunities. These shortfalls in their communities of origin have pushed them to look for alternative options abroad, in an attempt to fulfill their personal expectations, emigrants have left Mixteca with a future perspective of deprivation. For this reason, the assessment scores the lowest (color red in Table 12).

In contrast, scenarios 4, 6, 7 and 8 show that returning emigrants, mostly skilled workers with their own capital, are likely looking forward to pushing economic activity and alternative job creation in the region. These scenarios could envision the opportunity to foster conditions with equal prospects of development for inhabitants in Mixteca. These possibilities include not only economic activities but also education, social development and the wellbeing of the community. Under these circumstances, a positive assessment is provided (color green in Table 12)

C. Education

In addition to the previous two main ICoS goals, criterion *C. Education* is also addressed through the rule of *equal access for all people to information, education, occupation* in the third goal. The aim of the *C. Education* criterion should be to ensure that every member of the community has access to primary education, secondary education and can count on a structured occupational education with soft skills. It is compelling to promote the inclusion of indigenous and vulnerable members of the community, regardless of gender or background, to such an extent that Mixteca can reach not only economic but social development by people being involved in decisions that directly affect them.

Extending the concept provided in chapter 0, *education* relates not only to the acquisition and transmission of cognitive knowledge, but helps develop functional, ethical and personal dimensions that link complex knowledge, skills and attitudes useful for problem-solving competencies on a sustainable-valued framework. Hence, the purpose in targeting an occupational education including soft skills is to develop competences, mind-sets and actions to face the challenges that a holistic and sustainable system require to preserve the future development potential of the society. The end goal is to keep this system independent from governmental assistance funds or third-party funding.

Scenarios 1, 2, 3 and 5 in Table 12 anticipate a future where the basic right to quality education is not granted to all members of society. This means that equal opportunities of basic and secondary school completion, plus occupational education with soft skills are not available. By neglecting the education of vulnerable groups due to age, socio-cultural background, gender or ethnicity, the society might face a dysfunctional system restricting future economic, social and political development due to the lack of cohesion. This is the reason for the low assessment scores shown in color red in Table 12.

In an improvement over previous scenarios, the set comprised of scenarios 4, 6, 7 and 8, Cluster 2, shows partial accomplishment, allowing a completion of basic education, but not secondary or occupational education with soft skills. A limited education level where most community members benefit could see future partial improvement, not only in knowledge, but values, future perspectives and behaviors. Nevertheless, the full potential of the whole community would remain underdeveloped, since secondary education or structured occupational education might have limited availability. It could be possible that access is still restricted to vulnerable groups. Strengthening the opportunities of every member might enhance the community's economic and social development in the future. Therefore, since the target is not fully expected to be met, the assessment values show intermediate values represented with color yellow in Table 12.

S. Women's empowerment

The recognition of women as active members of rural communities is essential to sustainable development. Women should be granted opportunities to participate in the social, political or economic decision-making process. Not only integration but supportive mechanisms should be enforced to promote the empowerment of women to gain autonomy and be treated equally. Henceforth, the ICoS rule of *equal access for all people to information, education, occupation* applies to this criterion. Women contribute to Mixteca's development without being granted rights and opportunities, even though they account for more than 50% of the population in the area (see Figure 7 in chapter 0); the promotion of gender equality would bring justice and recognition to more than half the population.

In scenarios 1, 2 and 3 shown in Table 12, women face gender disadvantages limiting the recognition of their active participation in invaluable activities within their community - caring for the family, managing resources, acting as support provider when the partner is absent -. As a result, women's employment rates have decreased along with a lack of promotion. These barriers limit social development, affecting society's future; this set of scenarios will not fulfill its goal, consequently the assessment reflects the lowest scores (color red in Table 12).

Scenarios 5, 6 and 7 could anticipate limited recognition of women's performance in the daily activities of society; this recognition is revealed in the slight increase of women's employment rates; nevertheless, additional efforts are needed to recognize the value of women's performance in everyday activities in Mixteca. Partial fulfillment of the target is expected, expressed through the intermediate scores shown in the yellow cells in Table 12.

Scenarios 4 and 8 foresee an accomplishment of the target by displaying a substantial increase in women's employment rates. That being the case, the highest values on the assessment are seen in the green cells in Table 12. In these scenarios it could be perceived that women's needs, concerns, skills and contributions are taken into consideration in the decision-making process of the communities, thus entitling them to shared responsibility, providing equal access to and recognition of occupation and participation in the area.

9.4.2 Rule 3.2: Participation in societal decision-making processes

Following criteria will be addressed under this rule: *F. Population acceptance of renewable energy plans and participation, M. Cooperation between government, private investors, NGOs* and *T. Community organization.*

F. Population acceptance of renewable energy plans and participation

Population acceptance of renewable energy projects brings access to new opportunities to provide alternative economic benefits. It also brings a significant structural change by allowing members to take part in the decision-making process towards a sustainable future. A well-organized system should engage inhabitants by providing clear rules of participation and transparency in the decision-making process. Access to clean energy generation would allow communities to avoid exposure to air pollution, promote healthy cooking facilities, availability of electricity for productive uses and further development.

A wide array of scenarios: 1, 2, 3, 5 and 6 as shown in Table 12 might foresee a community whose members strive to participate in sporadic local solar energy projects, nevertheless, consistent and enduring projects are still needed to offer the conditions to participate in the development of the community's future path. Since the region has improved from its initial condition (lack of solar projects), an intermediate score is provided in the assessment (color yellow in Table 12).

Scenarios 4, 7 and 8 are likely to present the existence of at least one steady local solar PV project per municipality in Mixteca. The fulfillment of the target indicates that the interest and participation of all members of the community in the social decision-making process enable inhabitants to objectively judge, prefer and legitimize common decisions. Proposed constant renewable projects could have an arena of discussion and contest, live participation and active co-creation of a promising sustainable future, which is why the target is highly likely to be reached. The assessment scores are high, as shown in the green cells in Table 12.

M. Cooperation between government, private investors, NGOs

The development of society in Mixteca is linked not only to local actors or activities. Private companies and NGOs, from national or international contexts, could contribute to a successful energy system transition by promoting adequate strategies to resolve local challenges embedded in the global configuration, such as climate change, promotion of gender equality or poverty alleviation. Therefore, the criterion of *Cooperation between government, private investors and*

NGOs could be evaluated through the ICoS rule *participation in societal decision-making processes*. The robustness of this interplay among the three main stakeholders is revealed through the amount of loans destined to productive activities, as mentioned in the definition of targets in section 7.4. These should substantially increase to bring adequate support to the region. Government should provide an adequate framework that helps stakeholders formulate strategies for a systemic change (decarbonization plans, financing new energy projects)

Scenarios 1, 2, 3 and 5 in Table 12 are likely exhibiting a detachment among NGOs, regional government and private investors from civil society, which will likely see a sustainable future development in the area being evaded. These circumstances will impact in a lack of loans to promote productive activities in the region. The legal framework might not be functional or has rolled back, hence, interests and goals from civil society might seem mismatched among the different interested parties. Strategies need to be aligned to support the region's development. Therefore, the low sustainability scores in the assessment are presented in red color in Table 12.

On the contrary, scenarios 4, 6, 7 and 8 would likely see a supporting strategy provided by the interaction among NGOs, regional government and private investors towards civil society initiatives, to a large extent that will be impacted by development in the rural area. These initiatives will be supported by a substantial increase of loans to productive activities in Mixteca. The legal framework supports strategies in favor of a common goal such as an energy system transition; the path is likely enhancing a sustainable future; this is why the scores on the assessment are shown in green color in Table 12.

T. Community organization

Rural community self-organization shall be able to take decisions as a result of local interactions that allow the population to propose and promote decisions towards a sustainable future in a participatory context and structured format. The self-organization structure should be adapted to the local conditions and local circumstances. It should follow its course of action and promote community projects aiming for collective benefit, rather than being imposed by external actors and eventually failing; consequently, it is important for the *participation* of the members of the community in societal decision-making processes.

Almost all scenarios in Table 12 (except scenario 8) foresee a partial participatory process of community members. The efforts of the society grant the opportunity to express their preferences and judgments and be recognized as actors of change, under a context of sustainable action in the decision-making process. Nevertheless, the scarce or sporadic existence of community projects aimed at the collective productive benefit could mean that their active role is not sufficiently recognized, thus, slow development of the society could be expected. Community self-organization should not only include political or social decisions but a collective economic benefit too. On this account, a partial path to a sustainable future is revealed, so middle scores are shown in the yellow cells in the assessment in Table 12.

In scenario 8, the future in Mixteca will likely explore how society has matured in terms of social participation, and the implications of this evolution. The existence of at least one steady community project geared towards collective productivity is indicative of the (majority) community's members being afforded the right to voice their opinions and partake in decision-making processes concerning projects that advance the development of the society. An adequate community organization can be foreseen in this scenario, where self-awareness and actions about their future joint aspirations provide a plausible path to sustainability. Consequently, a high score in the sustainability assessment is indicated by the use of green color in Table 12.

9.4.3 Rule 3.3: Conservation of cultural heritage and cultural diversity

The interrelationship between native communities with their environment influences the future relationship of new ways of living. It influences the acceptance of modern energy systems without losing their identity by accepting and adapting to the change. Understanding the changes in the communities' way of living by the introduction of new technology is a cultural transformation of society. Hence, criterion *B. Ethnic identification* will be addressed under the rule *Conservation of cultural heritage and cultural diversity*. A sustainable transformation does not affect the culture from outside, but integrates / assimilates within it, calling for the conservation of cultural heritage and cultural diversity. This transformation will also impact the native language since it involves the interaction of the community with its environment (see section 7.4) and involves the transmission of the culture, customs and identity of Mixteca.

Scenarios 1, 4, 6, 7 and 8 in Table 12 could foresee an increase in the number of indigenous language speakers, reflecting the cultural ties of traditions, ethnicity, and language that shape how inhabitants live and work together, facilitating cooperation towards a common goal. As the number of native language speakers increases, the strength of the cooperative bond also increases. The integration of a solar PV energy system that preserves cultural diversity would be more likely to be accepted by the population, and there would be a higher willingness to take on new opportunities, thus leading to greater sustainability support. This is reflected in the high scores assigned in the green cells of the assessment in Table 12.

One step behind the previous set, scenarios 2, 3 and 5 may maintain or slightly increase the quantity of indigenous language speakers, thereby keeping a bond among the inhabitants. However, it should be desirable to increase and strengthen the bond so that communities could develop further their potential in which all members can work together under a common goal in a desired path to cultural sustainability. For this reason, these scenarios remain one step behind the desired goal of sustainability, as indicated by their intermediate evaluation scores (color yellow in Table 12).

9.4.4 Rule 3.4: Conservation of the cultural function of nature

Indigenous groups in Mixteca inhabit and change the natural ecological settlement and interact with the environment in a socio-cultural-ecological relationship. As a result, cultural values are born and are intrinsic to this particular socio-spatial region. The common understanding of environmental conservation considers mostly the economic value given to the natural resources; the cultural value or heritage is commonly disregarded or undervalued (Hernández Rodríguez et al., 2009). Mixteca is rich in cultural heritage resources key to local land use, which could define a partial rural economic system based on this natural heritage and even cradle rural tourism development. Cultural resources found in the ecological environment also remain, and remembrances of an ancient culture whose attitudes toward the environment constructed a heritage the current society in the region can enjoy. Therefore, the opportunity to build the link between the cultural function of nature and its sustainability cannot be neglected, so that future generations can also cherish and delight in the experience of landscapes and natural ecosystems. The suggested indicator to evaluate the criterion *B. Ethnic identification* within the *Conservation* *of the cultural function of nature* rule is the size of protected areas, since a loss of ecosystem decreases awareness and recognition of endangered species of flora and fauna, in addition to the loss of the land itself. The alternative use of land for other purposes than the preservation of natural resources is a sign of loss of cultural value, and an increase in urbanization without a proper reflection on a sustainable future.

The set of scenarios 1, 4, 6, 7 and 8 in Table 12 could likely foresee a strong interface between culture and nature originating as a result of an increase in protected areas, as well as strong land protection policies whose awareness of the ecosystem penetrates life in the rural communities in Mixteca. The biodiversity and ecological concern might be appreciated truly beyond the value of the individual resources, and the overall scenarios might represent a real defense of the cultural – biophysical - landscape of the region. Hence a high score is given in the evaluation, shown in color green in Table 12.

Scenarios 2, 3 and 5 might provide a light awareness of the protection of biodiversity and conservation and stagnation in the protected areas. The cultural-ecological attachment to the territory is not strongly articulated, and should be the subject of a political discussion to reinforce practices of stronger landscape protection. There seems to be interest from the societal perspective to increase conservation of the cultural function of nature and environmental-biodiversity discourse, but not enough to drive the path completely to a sustainable future, hence an intermediate assessment in yellow cells is shown in Table 12.

9.4.5 Rule 3.5: Conservation of social resources (tolerance, solidarity...)

The social cohesion of a society is important to promote an orientation towards a common path, hence the *conservation of social resources such as justice, tolerance, solidarity* (ICoS sustainability rule) are needed in addition to the economic factors. Criterion *D. Source of income* is addressed under this rule. The source of income, either by employment or receipt of remittances, conveys social actions contained in societal relations. For instance, remittance deliveries contribute to the social networks of relationships in which the trust of both sides (sender and receiver) is a vital component. Since the money transfers are an important contribution to the area, a proposed indicator is the value of remittances. It has previously been proposed to decrease the value of remittances to trigger local economic development to arise and reduce dependence on the external sources; however, remittance deliveries promote solidarity on an individual basis, trust, and openness to different forms of life. These social resources would / could be transposed to local employment where the same social resources can also be strengthened.

Since scenarios 1 and 2 in Table 12 foresee a future where the population will likely have a strong dependence on remittances, a lack of employment opportunities in the area might motivate a collective weakness of social relationships, low tolerance, and fragile social integration. Nevertheless, on an individual basis, there is a solidarity bond between the emigrant abroad and the relative in the community. Still, the need for a future perspective for the whole community is needed, where the social resources at a community-based level should prevail over the personal interest to reach development in the area. Consequently, the lowest assessment scores are assigned (color red in Table 12).

In scenarios 3 and 5 some possibilities to address the communities' economic and social development could arise, nurturing motivation and solidarity under these scenarios. However, fair social interests and justice are still not widespread at a collective level, since dependence on external funding still exists. Due to this partial dependence on remittances, the assessment shows an intermediate score (color yellow in Table 12).

In scenarios 4, 6, 7 and 8, remittances seem to decrease and capacity-building, jobs and investment opportunities increase. The income earned from labor provides the ability for the population not only to develop economically but also contributes to developing social networks of relations, and the formation of trust and self-confidence, ensuring social integration. More freedom and opportunities to earn their own income could make the inhabitants less dependent on remittances, and thus able to shape their private living conditions and at the same time enhance the future of the community in a just and equitable society. Thus, this set of scenarios score the highest in the assessment (color green in Table 12).

9.4.6 Summary of ICoS goal 3 assessment

Figure 31 below illustrates the sustainability assessment summary for ICoS goal 3 *Preserving society´s options for development and action*. Contrary to Figure 29 and Figure 30, the arrangement of scenarios is not strikingly defined to a specific cluster. Moreover, the scenarios do not completely overlap (except for the rules *conservation of cultural heritage and cultural diversity* and *conservation of the cultural function of nature* in both clusters) as shown in ICoS goals 1 and 2. This could be explained by the foreseeable circumstances in the future scenarios for Cluster 1. The assessment of the third goal of ICoS is the only goal which shows partial promising future scenarios within Cluster 1, contrasting with the pattern of the other two goals. Scenario 1 shows the highest score in the assessment in this cluster, shown in improved conditions mainly related to the conservation of cultural aspects (heritage and nature). The second scenario showing positive perspectives for change is scenario 5; even though this scenario does not show complete sustainable assessment, only three criteria scored as unsustainable, showing improvement on most of the criteria (6 out of 9). These encouraging findings provide perspective to the rural area and hints of hope for a sustainable future.

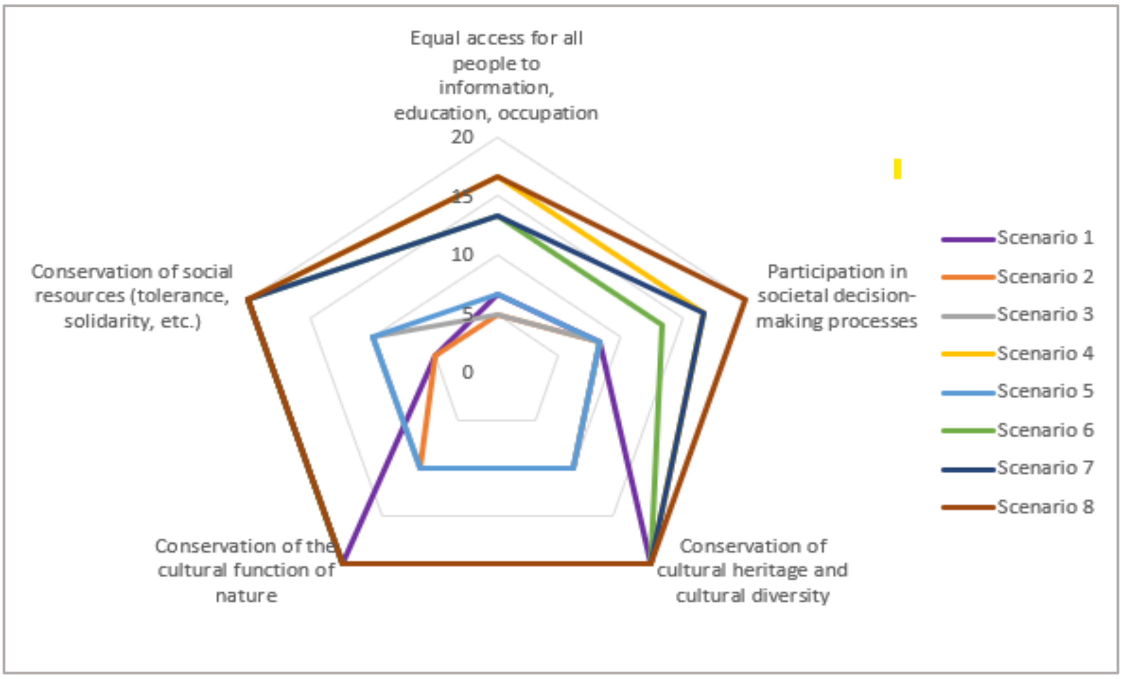


Figure 31. Graphical representation of the assessment of ICoS goal 3: Preserving society's options for development and action.

The four scenarios in the cluster 2 (scenarios 4, 6, 7 and 8) scored higher than those scenarios in the cluster 1 (scenarios 1, 2, 3 and 5), with seemingly good results and high expectations for a sustainable future. Among the best-performing scenarios 4, 6, 7 and 8, scenario 8 stands out from the rest since its highest score depicts a nearly sustainable future except for one criterion (*C. Education*). Thus, this scenario could be a role model for conditions in Mixteca.

A suitable construct of the society should consider *equal access for all people to information, education and occupation* (rule 3.1), thus, emigration can be avoided and women can be empowered. *Participation in societal decision-making processes* (rule 3.2) is a highly important social cohesion feature that can be promoted through adequate *F. Population acceptance of renewable energy plans and participation*; *M. Cooperation between government, private investors, NGOs*; and *T. Community organization*. The *conservation of cultural heritage and cultural diversity*, as well as the *conservation of the cultural function of nature* (rules 3.3 and 3.4) can be reached through the criterion *B. Ethnic identification*. Finally, the *conservation of social resources* (rule 3.5) can be explained through the criterion *D. Source of income*.

9.5 Summary of the assessment of the main goals of sustainability

Table 13 shows the summary points of each scenario of Mixteca's sustainability assessment, scored on the main goals towards the transition to a solar PV energy system. The lowest scores can be identified in scenarios 2 and 3, followed by 5 and 1. These four scenarios belong to the Cluster 1 identified in section 8.2. The highest scores are among scenarios 8, 4, 7 and 6 respectively; these are represented in Cluster 2. In order to allow the comparison between the scenarios, the values were normalized to 100. This procedure avoids a disadvantage on the total score assessment of the ICoS second goal *Maintaining society's productive potential* which was assessed under three rules (see section 9.3) while the other two goals were assessed under five rules each one.

Table 13. Summary of assessment of the main goals of the Scenario-based sustainability assessment for Mixteca scenarios

Goal	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Securing human existence	28.33	25.00	26.67	93.33	26.67	93.33	93.33	96.67
Maintaining society´s productive potential	26.67	25.00	25.00	96.67	25.00	96.67	96.67	96.67
Preserving society´s options for development and action	60.00	38.33	43.33	93.33	45.00	86.67	90.00	96.67
Total assessment points:	**115.00**	**88.33**	**95.00**	**283.33**	**96.67**	**276.67**	**280.00**	**290.00**

Figure 32 provides a graphic summary of the assessment for these eight scenarios. In the chart, two triangles can be distinguished, one smaller at the center and a bigger one, related to the two clusters of scenarios, a similar situation as in Figure 29 and Figure 30. The smaller triangle depicts the low scores resulting from the assessment of the scenarios 1, 2, 3 and 5 summarized in

Table 13. The bigger triangle reflects the higher scores of the sustainability assessment for the set of scenarios 4, 6, 7 and 8 (Cluster 2).

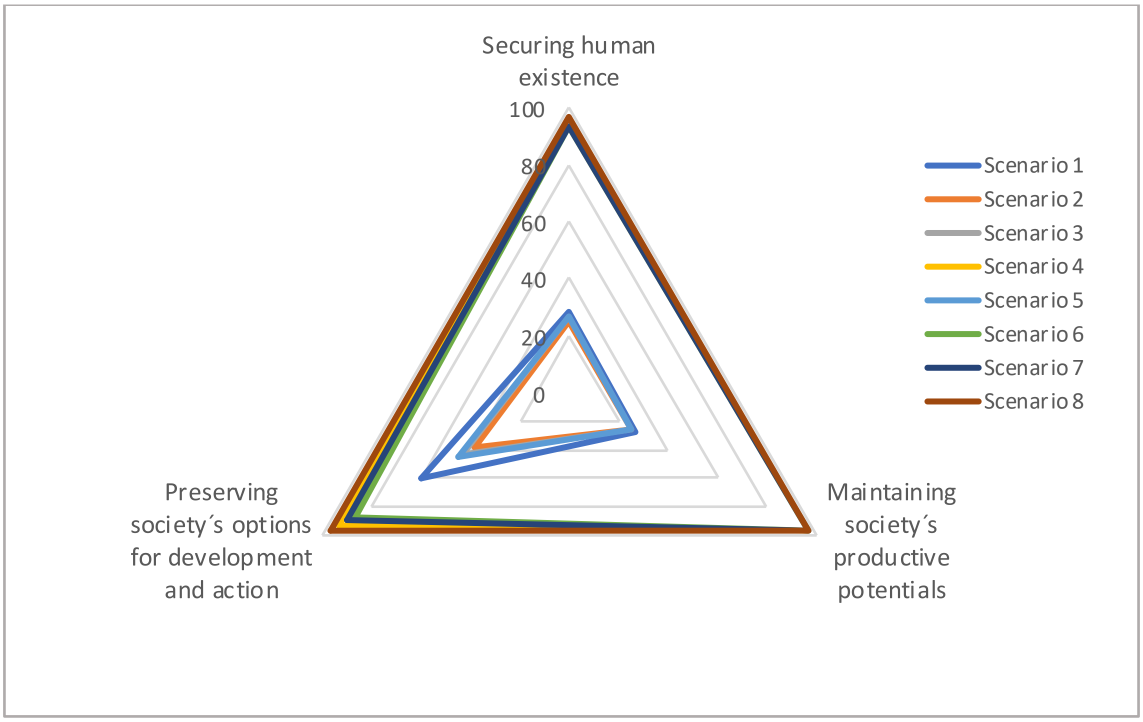


Figure 32. Graphical representation of the assessment of the three main ICoS goals related to the substantial rules

This inner figure illustrates that, from one side, the solar PV energy transition could bring an imbalance to sustainable priorities. Within the set of scenarios 1, 2, 3 and 5 (Cluster 1), the goal related to *preserving society´s options for development and action* has better performance than the other two goals in the same set (see above Table 13). Both remaining goals, *securing human existence*, as well as *maintaining society's productive* potential, remain underdeveloped with a pessimistic view of deterioration.

Scenario 1 stands among the rest of this set and could show better performance, although it cannot be said that its future looks sustainable. The only sustainable descriptor / criterion is *B. Ethnic identification*, whose scores in the assessment are the only ones with high marks. However, since it is a descriptor / criterion with low active influence (see Figure 26 in section 8.1), it is not enough to stir the system into the desired path.

There are only three descriptors / criteria with hints of sustainable performance: *A. Emigration*, *F. Population acceptance of renewable energy plans and participation*, and *T. Community organization*. Their intermediate scores in the assessment show a promising perspective, but these descriptors do not exert much influence in the system, and at the same time receive impacts from the rest of the descriptors / criteria (14 descriptors remaining), hence the whole system remains trapped in the unsustainable future. Primarily this means that the main benefits that a possible solar PV energy transition would bring will be translated into the increased number of indigenous language speakers, followed by bonding the emigrants with their communities of origin, and a receptive population working towards integrating the solar PV systems into their daily life.

Despite a moderate improvement in ethnic instances, a moderated community organization and an apparent acceptance of renewable energy, these seem to be isolated efforts within the society's ability to reflex into its situation and plan accordingly to reach an improvement in its own future. Society's ability of self-organization alone does not provide the required vision to drive society into a sustainable future. The partial accomplishment of one goal is not enough to avoid stagnation or setback in living conditions in Mixteca.

Therefore, the imbalance is reflected in the other two goals, showing high emigration rates, poor education level, and lack of basic services, which translates into population deprivation of basic needs still prevailing in the future. Low opportunities of employment with unfair wages leads to restricted subsistence based on income from own work, and high vulnerability to climate change in a region where the chances for a distribution of resources to future generations seem jeopardized, thus causing unavoidable effects on the population, endangering human health. The lack of rule of law restrict policies for the solar energy system implementation in the area; the cooperation among government, civil society and NGOs is unsuccessful and hard to achieve.

The failure to adequately implement a sustainable path under the set of scenarios 1, 2, 3 and 5 (Cluster 1) could be due to the combination of strong influences from the *governance uncertainties*, poor *legal system* and high impacts on *climate change*, identified in section 8.1 as drivers of the system. The population will not be organized and ready to face environmental impacts, since air emissions will not have been controlled; a lack of future perspective highlighted by a lack of reflexivity and steering ability would bring poor results in low investment in energy research. A failure in internalizing ecological and social costs will affect basic services access and an unequal provision among inhabitants. The lack of added value from solar energy will be due to the dependence on fossil fuels; there will be poor financial market strategy with high interest rates and no support for productive investments; unequal job opportunities and income disparities result in unfair trade conditions, hence gender impairment will persist.

In contrast, as mentioned before, Figure 32 also presents the future sustainable perspective of scenarios 4, 6, 7 and 8 in the bigger set of triangles. The future for Mixteca under this cluster of scenarios looks promising; their high scores in the assessment are evidenced in the Figure, more balanced than the previous set of scenarios. The scenario that stands out most is number 8, in which except for the descriptor / criterion *education*, the rest of the descriptors show the highest scores, thus, the perspective for poverty alleviation through the solar PV transition remains favorable and encouraging for sustainability. Given that changes in the education system of a region (and country) need a long time to permeate in the societal sphere - in addition to the corresponding costs - this might be the reason that efforts are still needed to move further under this criterion. Nevertheless, it can be affirmed that scenario 8 has the dominant opportunity for sustainability.

A re-examination of the third research question: "Is there a sustainable future that could promote poverty alleviation in the region?" (see chapter 0), is pertinent within the present analysis. None of the scenarios in this Cluster 2 comprises descriptors / criteria which scored insufficiently in the sustainability assessment, thus even the lowest-graded scenario 6, can be considered sustainable, as its main driving forces exert sustainable impacts triggering a cascading effect into the system, contributing to poverty alleviation. Those drivers with the least degree of sustainability are *C. Education*, *E. Basic service access*, *S. Women's empowerment*, *F. Population acceptance of renewable energy plans and participation*, and *T. Community organization*. All these descriptors (except women's empowerment) are within the tight interdependency of a complex system where at the same time as they exert influence, they also receive it. The descriptor *S. Women's empowerment* is the least active descriptor / criterion, which means it receives more influence than it could exert. Hence, the intermediate scores in the assessment are not enough to change the path of the system or downgrading it. Consequently, it remains within the promising sustainable future brought by the solar PV energy transition.

The re-examination of the second research question: "What could a sustainable future look like, and how could Mixteca achieve it?", (see chapter 0) leads us to the analysis of scenarios 4, 6, 7 and 8, where the energy transition would bring better instances for a sustainable future in most aspects; this indicates that society has learnt to balance goals and finds that addressing a secure existence is as important as maintaining the productive potential and preserving options for development and action. An overall improvement in performance compared to scenarios 1, 2, 3 and 5 (Cluster 1) could be expected. Consequently, conditions are suitable to alleviate poverty.

The low governance uncertainties along with an effective legal system have framed the conditions in the area to such an extent that the observance of the rule of law has made the corruption degree plunge, allowing for trust in the system providing a framework of hope and reliability in the institutions. Policies seem to back up the renewable energy production whose solar PV share foresees a significant increase. The acceptance and knowledge dissemination on renewable energy benefits contributes to the installation and growth of solar PV generation projects, increasing Mixteca's capacity-building and training young people, thus improving education levels compared to the status quo but not fully meeting its target of acquiring structured occupational education with soft skills. Nevertheless, efforts are on the path to a sustainable future. The transition to solar PV energy contributes to ameliorate climate change impacts. Basic services show an improvement, mainly driven by the solar PV energy supply, nonetheless, provision of water and drainage might still not be fully available to all the population.

The transition has allowed improvement of (self)employment opportunities, increased earnings and less dependence on remittances, in a seemingly prosperous *autonomous subsistence based on income generated from own work*. A reduction of emigration rates as well as returning emigrants contribute to the socio-economic development of the region. An increase in the economically active population along with a secure income are expected. The added value generated from the renewable energy system is being distributed within the communities and invested in the region, so the contribution to research and development in the state increases. The transition would fulfill the aim of poverty alleviation and uplift development in the region, reducing vulnerability.

Some considerations regarding the sustainability assessment need to be observed. First, not all the sustainability rules were analyzed, since some of them do not apply to the criteria used here; for example, the *Sustainable use of non-renewable resources* under the ICoS goal *Maintaining society's productive potential* does not apply to this case and has been omitted in the analysis. In other examples, the rule has been adapted, as in the instrumental rule, *Fair international economic framework conditions*, where this local case calls for national conditions before considering international circumstances. It is also worth noting that the rules needed to be adapted to the local conditions and to the pertaining criteria, as detailed in chapters 9 and 11 (e.g., the criterion *B. Ethnic identification* and rule *conservation of the cultural function of nature*). Furthermore, some criteria seem to relate to multiple rules, that is the reason, whenever applicable, one criterion is analyzed under several perspectives. This is the case of criterion *A. Emigration*, which is assessed through the three general ICoS goals; moreover, under the first goal, two sustainability rules are related: *Ensuring satisfaction of basic needs* and *Autonomous subsistence based on income from own work*. While in the other two goals, criterion *A. Emigration* was evaluated under one rule of each goal (*sustainable development of human-made, human and knowledge capital,* and *equal access for all people to information, education, occupation*).

9.6 Sensitivity analysis

After the sustainability assessment was concluded, a sensitivity analysis was performed. A sensitivity analysis evaluates how the results would change when varying the different parameters involved in the process and consequently, ensure the reliability and robustness of the results obtained (Singh et al., 2009). These analyses can be performed along the different stages and variable parameters of the assessment. Several factors could affect the outcomes of the *Scenario-based sustainability assessment* in this research. In the case of the scenario analysis, the noticeable factor affecting the results is the judgment assigned to each interrelationship between the descriptors. In the case of the sustainability goals, one of the factors influencing the results is the prioritization of the goals in the assessment, that is, the assignment of more weight to one (or more) goal(s) above others. As explained in sections 5.1.1 and 9.1 each rule has equal importance, regardless of the number of criteria addressed within it. Moreover, during the operationalization of the assessment, the total points assigned for the future sustainable assessment was evenly distributed among the number of criteria evaluated under each rule.

To validate the robustness of the assessment outcomes, the prioritization of some rules above others within the same goal was conducted in the first step. Then, a classification of relative importance was assigned among the three goals (in the second step). Within the goal *Securing human existence*, instead of the equal distribution of weight among its five rules (20% each), the rule *Ensuring satisfaction of basic needs* received 40% of the weight, followed by *Autonomous subsistence based on income from own work* (30%), and the remaining goals 10% each. For the second goal, *Maintaining society´s productive potentials*, the rule *Sustainable use of renewable resources* received 45% of weight, followed by *Sustainable development of human-made, human and knowledge capital* with 35%, and *Sustainable use of the environment as a sink for waste and emissions* with 20%. Finally, within the third goal, *Preserving society´s options for development and action*, the distribution was as follows; rule *Equal access for all people to information, education, occupation* received 40%, followed by *Participation in societal decision-making processes* with 30%, and the rest with 10% each. In the second step, the first goal *Securing human existence* was assigned the highest preference (50%), followed by *Maintaining society's productive potential* (30%), and finally *Preserving society's options for development and action (20%).* Table 14 below shows the summary points of this process.

Table 14. Sensitivity analysis on main goals of Scenario-based sustainability assessment for Mixteca scenarios

Goal	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Securing human existence	49.33	40.00	44.00	138.67	44.00	138.67	138.67	149.33
Maintaining society´s productive potentials	26.75	25.00	25.00	96.50	25.00	96.50	96.50	96.50
Preserving society´s options for development and action	38.67	28.00	30.00	70.67	32.67	61.33	65.33	74.67
Total assessment points:	**114.75**	**93.00**	**99.00**	**305.83**	**101.67**	**296.50**	**300.50**	**320.50**

Figure 33 below illustrates the resulting representation of the new arrangements. It shows the two sets of clusters represented in two triangles, similar to those shown in Figure 32. The smaller triangle in the center represents the set of scenarios 1, 2, 3 and 5 (Cluster 1) and the bigger triangle represents the set of scenarios 4, 6, 7 and 8 (Cluster 2)

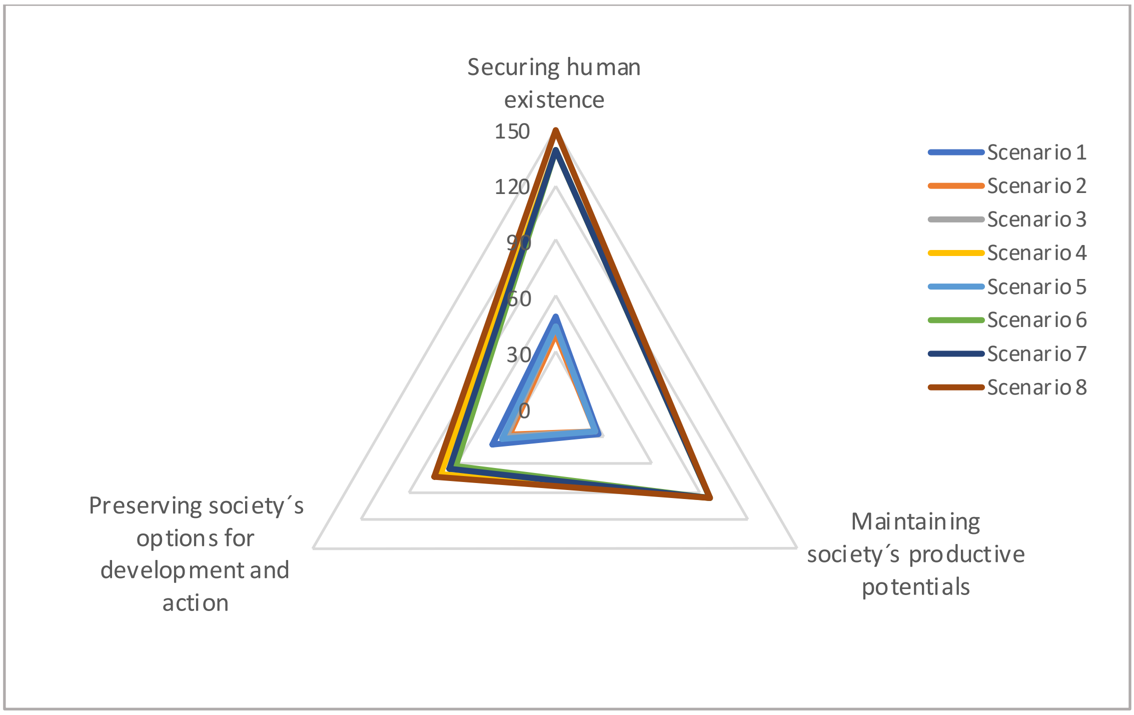


Figure 33. Sensitivity analysis of the ICoS main goals assessment without weighting consistency

If we compare the findings of this sensitivity analysis with those of the sustainability assessment under weighting consistency, the results corroborate the two well-defined clusters and the scenario configuration within each cluster. In both cases the same pattern is followed by the scenarios comprised within the cluster. This is, scenario 8 stands out among its set (Cluster 2) as that which promises the most sustainable future. The same can be discerned among the first set of scenarios (Cluster 1), where scenario 1 shows the least *un*sustainable future. The shape of the triangles is a reflection of the weight assignment, the first goal, of *Securing human existence*, receives the highest priority, followed by *Maintaining society's productive potential*, and at the end, *Preserving society's options for development and action*.

It seems in both cases that the main distinctions among scenarios take place mostly on those criteria related to preserving society's options for development (criteria: *F. Population acceptance of renewable energy plans and participation*, *T. Community organization*, *B. Ethnic identification*) whose assessment is slightly distinguishable from the main path. The scenarios are not totally dissimilar, since the evaluation does not provide strong contrasts among them. The drastic contrast is what brings the main difference between Clusters 1 and 2.

The sensitivity analysis was repeated several times varying the prioritization of some rules above others in a first step, and changing the classification of relative importance among the three goals as a second step, distributing the weight differently each time. The purpose was to identify a combination of weights that would show a different ranking of scenarios as the initial identified order where scenario 8 shows as the most sustainable and scenario 2 as the least sustainable (see section 9.5). In all cases, the configurations and rankings of scenarios are the same as the ones shown in Table 13 and Table 14 where the scenarios are ordered from most sustainable (highest scores): 8, 4, 7 and 6 respectively, these scenarios are represented in Cluster 2. The lowest scores were identified in scenarios 2 and 3, followed by 5 and 1. These four scenarios belong to the Cluster 1.

The results of the sensitivity analysis overall indicate that the similarities between the configuration of scenarios and patterns are maintained despite the assignment of priorities to certain goal and rules. Therefore, it can be assumed that the S*cenario-based sustainability assessment* performed shows reliable results on the current conditions of the Mixteca case.

9.7 The instrumental rules assessment

As explained in section 5.1, ICoS makes a distinction between the fundamental (underlying, essential) requirements to meet sustainability, through the substantial rules, and the way to meet these requirements - the instrumental rules. These instrumental rules or 'how-rules' are therefore concerned with the question of the institutional, political and economic framework conditions that would have to be in place to put sustainable development into practice.

This section evaluates the sustainability of the conditions that need to be met in Mixteca to achieve a future sustainable development. Table 15 below provides an overview of the assessment of the different criteria assigned to the instrumental rules. A detailed explanation of the assessment is provided in the following sub-sections. Of the ten instrumental rules of ICoS, two of them are not addressed: *limitation of public debt* and *promotion of international cooperation*, since they do not apply to this case, as explained in section 7.5.

Table 15. Assessment summary related to the instrumental rules of ICoS

The instrumental rules: assessment of the framework conditions		20	10	5	**Cluster 1: "Back to XIX Century"**				**Cluster 2:"Hope for a better future"**			
Sustainability rule	**Criterion**	**Evaluation reference**			**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 5**	**Scenario 4**	**Scenario 6**	**Scenario 7**	**Scenario 8**
Internalization of ecological and social costs	E. Basic services access	Every inhabitant has access to reliable basic services	Not every inhabitant has access to all basic services or has partial access to them.	Part of the population has restricted or no access to basic services.	1.67	1.67	1.67	1.67	3.33	3.33	3.33	6.67
	N. Added Value	A substantial added value generated from solar sources in the area	A minor added value generated from solar sources in the area	A decrease of added value generated from solar sources in the area	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	Q. Climate change	A substantial increase in solar energy share	A meager increase in solar energy share	No contribution to solar energy share	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
Adequate discounting	O. Financial market in rural economy	Considerable decrease of interest rates of loans for productive activities	Minor decrease of interest rates and loans from non-banking institutions	High interests rates and impossibility to access credits	5	5	5	10	10	10	10	10
Fair (inter)national economic framework conditions	D. Source of income	Remittances decrease and capacity building, jobs, investments increase	Partial dependance on remittances	Strong dependance on remittances	2.50	2.50	5	5	10	10	10	10
	G. Job and earnings	Considerable decrease of population below minimum wage	A light decrease of population earning minimum wage	No change or increase of rate of population below minimum wage	2.50	2.50	2.50	2.50	10	10	10	10
Society's ability to respond	R. Environmental effects on population	Decrease of air pollution particles to meet national standards	Maintaining current levels or minor decrease of air pollution particles	An increase of air pollution particle or lack of monitoring	1.25	1.25	1.25	1.25	5	5	5	5
	S. Women's empowerment	Substantially increase women's employment rate	Slight increase of women´s employment rates	Lack of promotion and decrease of women's employment rates	1.25	1.25	1.25	2.50	5	2.50	2.50	5
	B. Ethnic identification	Increase of the quantity of indigenous language speakers	Maintaining the same quantity of indigenous language speakers or minor increase	A decrease of the quantity of indigenous language speakers	5	2.50	2.50	2.50	5	5	5	5
	D. Source of income	Remittances decrease and capacity building, jobs, investments increase	Partial dependance on remittances	Strong dependance on remittances	1.25	1.25	2.50	2.50	5	5	5	5

Society's ability of reflexivity	B. Ethnic identification	Increase of the quantity of indigenous language speakers	Maintaining the same quantity of indigenous language speakers or minor increase	A decrease of the quantity of indigenous language speakers	5	2.50	2.50	2.50	5	5	5	5
	J. Investment in RE research	Significant increase of investments in energy research	A meager increase of investments in energy research	Reduction or stagnations of investment in energy research	1.25	1.25	1.25	1.25	5	5	5	5
	S. Women's empowerment	Substantially increase women's employment rate	Slight increase of women´s employment rates	Lack of promotion and decrease of women's employment rates	1.25	1.25	1.25	2.50	5	2.50	2.50	5
	C. Education	Basic and secondary school completion, plus occupational education with soft skills	Allowing partially some years (from 5 to 9) of education	Withholding the basic right to a quality education	1.25	1.25	1.25	1.25	2.50	2.50	2.50	2.50
Society's ability to govern	H. Governance uncertainties	Increased satisfaction of level of governance	A minor satisfaction of level of governance	Reduced satisfaction of level of governance	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	I. Policies f/RE	A substantial increase in solar energy generation	Slight increase of solar energy generation	Decrease of solar energy generation	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
	P. Legal System	Significant reduction of corruption levels	Minor reduction of corruption levels	No reduction or increased levels of corruption	1.67	1.67	1.67	1.67	6.67	6.67	6.67	6.67
Society´s ability of self-organization	F. Population acceptance of RE	Existence of at least one steady local solar PV project per municipality	The scarce or sporadic existence of local solar energy projects	The lack of local solar energy projects	5	5	5	5	10	5	10	10
	T. Community organization	Existence of at least one steady community project aimed at the collective productive benefit	The scarce or sporadic existence of community projects aimed at the collective productive benefit	A decrease or no promotion of community projects aimed at the collective productive benefit	5	5	5	5	5	5	5	10
Balance of power between societal actors	M. Cooperation between government, private investors, NGOs	Substantial increase of loans to promote productive activities	Minor or scarce loans to promote productive activities	Lack of loans to promote productive activities	5	5	5	5	20	20	20	20

Scale used: 5 (red) if the target is highly likely to be missed; 10 (yellow) if the target is anticipated not to improve or slightly improve; 20 (green) if the target is expected to be accomplished.
The letter assigned to the criterion (second column) corresponds to the reference letter on the descriptor/criterion (see Table 8).

9.7.1 Rule 1: Internalization of ecological and social costs

Three criteria are analyzed to address this rule: *E. Basic services access (water, electricity, drainage), N. Added Value* and *Q. Climate change.*

E. Basic services access (water, electricity, drainage)

The criterion *E. Basic services access (water, electricity, drainage)* can also be assessed through the instrumental rule *Internalization of ecological and social costs*. Given that there is a lack of basic services coverage in the area, it would be desired that production patterns are aligned with innovation and efficiency to preserve the resources for future generations; i.e., it is strongly suggested that electricity supply in the area should come from renewable sources instead of supporting fossil fuels. Electricity is also required in most cases to supply water to the communities, and the ecological cost of a fossil fuel operation is without doubt higher than the financial cost. Nevertheless, most decisions are taken solely on a budget basis, which in turn is translated to the user. A support scheme would be needed to assist inhabitants to carry the burden of an economically expensive system with social-ecological benefits, and long-lasting structures of basic services supply. Consequently, the proposed indicator is the population coverage of basic services with a desired target to provide full coverage in the area based on the sustainable premise of “leaving no-one behind”.

Scenarios 1, 2, 3 and 5 (Cluster 1) in Table 15 anticipate a restricted or lack of access to basic services for a section of the population, which may not properly reflect the environmental and social costs incurred in their production. It could be the result of lack of data availability and valuation, unsuitable working conditions, as well as lack of institutions to reflect and react to future supply and scarcity. As a result, a shortfall of basic services may prolong poverty, hindering the path to a just and resilient future. Accordingly, the lowest score is assigned in the assessment (color red in Table 15).

Scenarios 4, 6 and 7 in Cluster 2 seem to show efforts to provide the minimum level of provision of elementary basic services, nevertheless, not every inhabitant has access to all basic services, or partial access. This supply seems to not entirely associate with and / or support environmental and social costs. The supply, quality and reliability of basic services might be at the expense of some resource’s depletion, mainly water. Energy services might be supplied through solar PV, however, the cost of technological change needs to be carefully accounted for. Consequently, an intermediate score is assigned (color yellow in Table 15).

Scenario 8 visualizes the provision of reliable basic services for all, and it seems this is the only scenario that could consider the environmental and social costs associated with this provision. Accounting for the external costs could help diminish resource scarcity and prevent damage to ecosystems, as well as help fair labor conditions. To this end, the highest assessment points are assigned (color green in Table 15).

N. Added Value creation from the renewable energy sector

The economic performance of projects from renewable sources is required to an extent to allow society to work and be maintained through the production of goods and services. These can serve their own needs or incorporate them into (inter)national trade processes. Knowledge is also an added value creation that can be translated into policy goals to support renewable energy systems creation. Experience and skills are acquired through jobs that stimulate different industries in the local or national economy.

Scenarios 1, 2, 3 and 5 in Table 15 consider that there is a decrease in added value generated from solar PV energy generation sources in the area, thus, it is further from a sustainable future. Compliance with social, working and environmental standards during the added value creation might be mostly unaccounted for. Consistent effort still needs to be promoted to sustain human progress in future generations. For this reason, the lowest assessment scores are shown, (color red in Table 15).

On the contrary, scenarios 4, 6, 7 and 8 foresees a substantial added value generated from solar PV sources in the area, through job opportunities, investments, education, and availability and reliance of electricity used for productive uses. These scenarios pave the way for a just transition. Compliance with social, working and environmental standards during the added value creation seems to be mostly accounted for. A sustainable future is a promising pathway under these scenarios, hence the highest valuation in the assessment (color green in Table 15).

One immediate added value of the energy system transformation would be the switch of energy provision from the fossil source to a renewable source. This change would benefit the environment and people. Assuming the people own the means to produce the energy, i.e., solar cells, the population would be supporting its development, providing benefits and gains supporting its distribution. Cooperative groups formed by the civil society would increase their wellbeing guaranteeing their income generation, and strengthening the bond to work (social understanding) accounting for a reliable service with productive uses.

Q. Climate change

From the economic point of view, the natural capital has been assigned a price that does not necessarily reflect its real value or importance to our ecosystem. In Mixteca's case, the degradation of land, water and air pollution are some of the factors not considered within the economic system, which also contribute to impacting on climate change. The increased use of resources to satisfy basic needs could lead to scarcity in the future; the introduction of new species of flora and fauna could also lead to deforestation and depletion; increased emigration in search of better opportunities for employment and education would leave the area without a working population; the rural areas used as sinks for waste from the urban regions could end up abandoned. Unsafe or unhealthy working conditions could increase the costs of health treatments in the future, raising the costs of elderly care too.

An increase in renewable energy share, in Mixteca's case solar energy production, would help ameliorate and contribute to the fight against the impacts of climate change by showing appreciation of the ecological impact of avoiding using fossil fuels sources.

Scenarios 1, 2, 3 and 5 in Table 15 appear to have failed to meet their target of increasing solar energy share, as well as to recognize the value of the ecological system. Furthermore, the continued production of energy through fossil fuels has the potential to adversely affect human and ecosystem health, leading to increased air emissions and environmental liabilities. Additionally, increased production volumes with the aim of reducing costs could result in the depletion of natural resources. On the social side, the excessive efficiency of labor forces in the small factories in the area could lead to unemployment and an imbalance of social wellbeing.

These factors are reflected in the lowest assessment scores, which are highlighted in color red in Table 15.

The scenarios 4, 6, 7 and 8 could likely provide a better value and appreciation for the ecosystem's natural capital, hence the generation and substantial increase of solar energy production would increase and could likely meet the target. Special attention needs to be paid to increasing productivity as it could mean excessive use of natural resources and unemployment due to labor efficiency. A balanced ratio is required to be considered sustainable. Adopting suitable measures could help alleviate possible negative impacts in the future, providing a better opportunity for future generations to benefit from natural resources and better working conditions. A positive (green) assessment is provided (color green in Table 15).

9.7.2 Rule 2: Adequate discounting

The selected criterion addressing this rule is *O. Financial market in rural economy.*

Credit for productive purposes is a means to improve someone's living conditions. When credit is used for job creation, self-employment, asset investments, education, or to create a better physical condition of living, sustainable development is reached. Moreover, the amount of debt should be connected to the feasibility of the borrower's capacity to pay it off. Adequate conditions for borrowing practices should avoid the need to transfer most or a substantial part of income to pay debts, as well as the methods of borrowing in harmful conditions (without full disclosure of conditions, fees, and interest rates presented in a deceptive way). It is desirable that an appropriate interest rate should be allocated for the rural region and made available to inhabitants so they can (self)-finance productive projects or renewable energy projects without endangering their future, or their children's future. Encouraging productive activities through accessible financing would boost the inhabitants' progress on their own capital; the possibility to manage their own assets would contribute to maintaining the community working and subsisting on its own means.

Scenarios 1, 2 and 3 in Table 15 could likely show high interest rates and a lack of access to productive credit that would constrain the development of the region's potential. The absence of financing supporting institutions, as well as high-interest rates, could hinder the development of productive activities, perpetuating the poverty cycle. There may also be a lack of coordination and ability for the self-organization of society, where strategies are missing to build strong financial institutions. For this reason, the lowest scores are given to the evaluation, shown in color red in Table 15 as a sign of failure to reach the target.

Scenarios 4, 5, 6, 7 and 8 could reveal a minor decrease in interest rates of loans from non-banking institutions, nevertheless, since these informal organizations might be non-regulated sources, higher risks are incurred. The high interest rates that an informal moneylender could provide under these scenarios seem inclined to limit the productive potential of the community, hindering its future progress. A weak financial system might also be a reflection of a lack of self-organization within the society. Stronger measures might be needed to evolve and dispose of adequate financing institutions at appropriate interest rates. As a consequence, an intermediate score is assigned in the evaluation due to a partial fulfillment of the target (color yellow in Table 15).

9.7.3 Rule 4: Fair (inter)national economic framework conditions

This rule is addressed by two criteria: *D. Source of income* and *G. Job and earnings*.

D. Source of income

Mixteca's economic network should be designed openly and clearly to promote the participation of all capable inhabitants willing to shape the economic development of the region. Consequently, a new way of organization could arise where transportation, financial systems, production, distribution and supply are adapted to the area's needs, bringing fair participation to their population, thus trying to avoid as far as possible transfer of fees or surcharges outside of the area for services provided. For this condition to apply, an equal distribution of opportunities and participation should prevail.

Scenarios 1 and 2 in Table 15 could anticipate the lack of suitable labor conditions and a rise in unemployment; these conditions could promote trading marginalization within the area and between other communities, restricting its access to a further scale (state-nation). A strong dependence on remittances might be the only available way to access a secure income. A future livelihood might not be guaranteed under these scenarios. For this reason, the target is likely to be missed, as shown in the low scores in the assessment (color red in Table 15).

Scenarios 3 and 5 are likely showing incipient conditions for fair wages in a step into a future economic integration. Nevertheless, independence from remittances is not yet achieved. Acceptance of a fair labor environment in the area is the first step to poverty alleviation, although conditions in the area are still in the early steps of development to promote the needed change for a local-state inclusion. The source of income depends partially on remittances due to the limited availability of fair employment, hence partial fulfillment of the target is achieved, shown in the yellow cells of the intermediate scores in Table 15.

A significant improvement in scenarios 4, 6, 7 and 8 show economic growth at the regional level. Fair labor conditions seem to prevail in the area, these conditions could provide the opportunity to participate in the state and national economic chain and decrease dependence on external income provided by remittances from emigrants abroad. The gap between wages and working conditions compared to urban regions might be narrowing if the labor standards are maintained by improving living conditions in the rural region. It is worth noting that fair salaries and adequate working conditions are framed and supported by national standards, thus, local expectations should be in line with these main conditions. Further analyses should be conducted on subsidies and state contributions to assert that a reasonably equitable distribution of income is in place. This set of scenarios shows a promising fulfillment of the sustainable target, thus the high assessment is expressed in green color in Table 15.

G. Job and earnings

As mentioned in the previous criterion, all members of the community should have the possibility to ensure a means of subsistence by an employment or occupation that contributes to the economic development of the region, earning a fair income to live a dignified and just life. Indigenous, poor and other vulnerable groups in rural regions are victims of disadvantaged working conditions; employers benefit from this situation by offering unfair salaries due to lack of job opportunities. To this group can be added the sector of the population which has been marginalized as a consequence of environmental degradation, suffering scarcity of water, or noise and pollution due to manufacturing companies. These companies are granted parcels and use of natural resources under the premise of job creation, regardless of the job conditions. In this situation, neighboring communities are affected, as well as the low-waged employees. The high discrepancies between the employer and employees’ salaries should be avoided; the provision of equal opportunities for everyone should be available. The economic growth of the communities should avoid disproportionate income disparities, to target better and uniform living standards among inhabitants.

Scenarios 1, 2, 3 and 5 in Table 15 exhibit that the lack of employment, along with poor working conditions and low wages, could restrict the economic development of the population, hence its wellbeing and activities depending on economic welfare like education, healthcare, or cultural and social activities are jeopardized. These restrictions might prevent the rural area integrating into the state or national fair economic chain, or mean it is subject to additional taxes or increased interest rates to the detriment of the population. Given the increased rate of population below minimum wage, the target is missed and the lowest scores are shown in the assessment (color red in Table 15).

In contrast, scenarios 4, 6, 7 and 8 display an increased integration of the population in economic activities, due to the possible availability of jobs with fair wages and conditions that could foresee integration of the local area's economic activities into the state-national and further global fair-trade chain. These conditions could trigger additional benefits such as reduced interest rates for financing and opportunities to trade at lower/fair tariffs. It could also stimulate an economic improvement for the population in the rural area. Wages and working conditions are aligned to national regulations, hence a considerable decrease in the population rate below minimum wages. The gap between urban and rural income seems to be narrowing, although additional analyses need to be conducted to assert a reasonable and equitable distribution of income and contributions within the different localities and states. The positive outcome is shown in the high assessment values (color green in Table 15),

9.7.4 Rule 6: Society's ability to respond

Mixteca society should be prepared to perceive, react and adapt to challenges in its natural or social environment to fully develop its transformation potential and achieve a better standard of living. The criteria chosen to analyze this rule are: *R. Environmental effects on population, S. Women’s empowerment, B. Ethnic identification* and *D. Source of income.*

R. Environmental effects on population

Scenarios 1, 2, 3 and 5 in Table 15 reveal that despite the increase in pollutant levels, society in Mixteca does not seem to react adequately to take corrective action. In addition, the increase in the number of chronically-ill people caused by the polluted air particles could also be a reflection of the lack of satisfactory response to corrective actions. The impact on health is not only an ecological problem but also an economic and social challenge due to the growing inequality among the population in the rural area that requires a comprehensive solution to stop the degradation of air and natural resources. As a consequence, low values are assigned in the assessment, whose future is likely missing its target (color red in Table 15).

Scenarios 4, 6, 7 and 8 could anticipate a decrease in pollutant levels in the area, as monitoring meets national standards, i.e., reaching its target; this situation seems to reflect the ability of society to take corrective action on relevant environmental disruptions. The impact on health requires a holistic solution to stop the deterioration of the environment. Cultural transformations of practices might seem to also contribute to keeping low levels of air pollutants. In addition, reducing the environmental effects on the population could considerably reduce the social and economic costs associated with the treatment of life-threatening diseases, and as a consequence, the population could aspire to a better quality of life. Appropriate measures seem to be considered to stop the future threats and take corrective action in a satisfactory period of this cluster of scenarios. Positive assessment is reflected in color green in Table 15.

S. Women's empowerment

The scenarios 1, 2 and 3 presented in Table 15, show the limited perception of women's value within the socio-economic context in Mixteca. Despite their efforts, women will continue to perform activities that will remain unrecognized as value-added, hence, women's employment rates show a decrease. Society under this set of scenarios is unable to react and include women's potential as part of a structural social condition. As a consequence, these scenarios will not foresee a sustainable development and reflect the lowest scores in the assessment (color red in Table 15).

Scenarios 5, 6 and 7 could show some institutional measures planned for the future, e.g. equal education opportunities, awareness on gender equality, availability of opportunities to access leading positions within the (local) government. However, concrete actions are still limited, hence partial fulfillment of the target could anticipate a slight increase of women's employment rates. Therefore, these scenarios get the intermediate scores shown in the yellow cells in Table 15Table 12.

Scenarios 4 and 8 foresee a fulfillment of Mixteca's social system to recognize women's contribution to socio-economic life in the area. Effective inclusion of women's activities is embedded in the structural functional system in the area in these scenarios. Society has acquired the ability to respond to societal challenges by promoting a substantial increase in women's employment rates and fulfilling the target. For these reasons, the highest values are seen in the assessment (green cells in Table 15).

B. Ethnic identification

Scenarios 1, 4, 6, 7 and 8 in Table 15Table 12 seem to perceive a mature society in Mixteca able to respond to the inclusion of indigenous groups within a participative social system. The inclusion of the indigenous people's needs in the decision process is pivotal because it allows that the solar PV energy system could be adapted to promote their development, provide for economic activities that improve their wellbeing. A sense of belonging is promoted among these groups that strengthen their ethnic identification. As a result, an increase in the number of indigenous language speakers is expected meeting the sustainability target, thus, high scores are assigned in the assessment (color green in Table 15).

Scenarios 2, 3 and 5 may show that society in Mixteca has developed the ability to perceive the need to provide additional support to indigenous groups, however the capacity to react has not been strong enough to change the social conditions they are immersed in. For this reason, the communities have not reached yet their full development potential. A slight increase in the quantity of indigenous language speakers could be expected and intermediate evaluation scores are assigned (color yellow in Table 15).

D. Source of income

The limited ability of society in Mixteca to respond to socio-economic concerns and provide adequate sources of income, i.e. job opportunities, leads to a future in which dependence on remittances is the alternative for scenarios 1 and 2 in Table 15. The awareness ability to perceive the structural challenge of income sources remains underdeveloped. These scenarios are likely to miss the target, they seem to extend the status quo where their future looks unsustainable. Consequently, the lowest assessment scores are assigned (color red in Table 15).

In scenarios 3 and 5, there is a perceived lack of solid responses to the structural challenges of the region's socioeconomic system. Plans are outlined to overcome this shortcoming, but the corrective measures are not sufficiently implemented or the reactive strategy is not sufficient to create the necessary development. Partial dependence on remittances as a source of income continues to prevail, hence the assessment shows an intermediate score (color yellow in Table 15).

In scenarios 4, 6, 7 and 8, society in Mixteca has developed and achieved the resonance capacity to adjust the institutional framework and create the conditions for investments, capacity building and job opportunities needed. As a result, a decrease in dependence of remittances takes place while an increase of employment or income sources are perceived. The sustainable target is expected to be met, thus, this set of scenarios score the highest in the assessment (color green in Table 15).

9.7.5 Rule 7: Society's ability of reflexivity

Four criteria were chosen to assess this rule: *B. Ethnic identification, J. Investments in energy research, S. Women's empowerment* and *C. Education.*

B. Ethnic identification

Society in Mixteca should consider the consequences of lack of integration of the different ethnic groups - or adequate integration - within its organization in order to fully function as a harmonious social system. This way, situations oriented to specific groups or sectors within the community can be assessed and solved in a networked coordinated process. The identification of each ethnic group's needs is important to align them to a common path. The recognition of the indigenous language speakers and its support strengthen the ties within the group.

Scenarios 1, 4, 6, 7 and 8 in Table 15 could envision a society in Mixteca that appears to have integrated its cultural traits and created suitable institutions that recognize the cultural aspects interrelated with the ecological, economic and social dimensions. Thus, common goals as a society could be pursued in an integrated institutionalized process. The growing number of indigenous language speakers under these sets of scenarios is a reflection of the society's ability to preserve its cultural dimension. By accepting and integrating their diversity, society seems to battle inequality, and opportunities could be provided to expand human capabilities. For these reasons, the assessment results show high scores (color green in Table 15).

Scenarios 2, 3 and 5 could see a partial integration of cultural aspects in Mixteca, where society might see a minor increase in the number of indigenous languages speakers; nevertheless, the future under these scenarios might not be sufficient to establish institutions that integrate ecological, economic and social aspects into the common goals of society to battle inequality and support poverty alleviation. Since additional efforts are needed to meet the sustainability goal, the assessment shows an intermediate valuation (color yellow in Table 15)

J. Investments in energy research

The communities in Mixteca should be able to reflect on their alternatives about their future development; energy supply through renewable systems could shape a sustainable future for which they should assess how the different dimensions - social, economic, environmental, political – interact, and anticipate their outcomes so that the best alternative can be taken in a coordinated effort. The indicator *expenditure on renewable energy research by Federal Government and the Federal States* could provide an overview of how fossil fuels are replaced by renewable energy in a path to a sustainable future.

Scenarios 1, 2, 3 and 5 in Table 15 foresee a society that is unable to plan long-term investments in energy research due to a lack of vision. The probable advantages would be mostly planned for specific groups more on an individual basis than for future collective benefits. A common pathway to improve living conditions would require cooperation and collaboration between multiple actors as levers of change; under this set of scenarios, societal institutions could likely fail to fulfill a conjoint future goal, thus a reduction or lack of investment in energy research follows. As a result, the poor grading in the evaluation (color red in Table 15).

In contrast, society in Mixteca in scenarios 4, 6, 7 and 8 could be more perceptive of the potential for substantial benefits to rural communities in the future that could be realized through increased investments in renewable energy research. The benefits, as well as drawbacks, could have been anticipated even before investments have been produced. Society has envisioned a chain reaction in which economic, societal and environmental issues are intertwined, and solid institutions could facilitate the connectivity among its different dimensions. In consequence, a significant increase in investment in energy research is likely to take place, meeting the sustainable development goal, illustrated in color green in Table 15.

S. Women's empowerment

The recognition of women's contribution in the social, economic and ecological realms of Mixteca daily life shows the faculty of the inhabitants to consider women's capacity and potential to develop further. Making use of society's reflexivity capacity, the recognition of women as powerful agents of change would empower and prepare them to make better decisions for the benefit of the community.

In scenarios 1, 2 and 3 of Table 15, a lack of commitment from the society to recognize women´s capabilities and participation in the economic, societal and political dimensions would prevent women from earning empowerment; as a result, a decrease in women's employment rates, as well as education levels, do not allow to foresee an integrated development in the area. Therefore, the low numbers in the sustainability assessment, marked in color red in Table 15.

In scenarios 5, 6 and 7, a meager recognition of women´s capabilities and restricted participation in the economic, societal and political dimension has stopped women from fully developing and receiving a thorough recognition for their performance; as a result, a slight increase in employment rates is observed, however, this is not enough to fully empower women in the area. Subsequently, intermediate scores are reached in the evaluation, shown in color yellow in Table 15.

In scenarios 4 and 8, the solid commitment from the society to recognize women´s capabilities and participation in the economic, societal and political dimensions could transform the sensitivity of the gender parity; policies and programs encourage women’s empowerment, as a result, an increase in employment rates could foresee an integrated development in the area. Thus, the highest values on sustainability are provided (color green in Table 15).

C. Education

Scenarios 1, 2, 3 and 5 exhibited in Table 15 are the result of the absence of reflexivity in the socio-economic conditions of Mixteca. The strategy of investing less in long-term public goods such as education because the results are not immediately perceived, contributes to inequality and scarce development. This shortsighted reflection on socio-economic results prevents Mixteca from foreseeing the consequences, normalizing the poor results in education in the future. Hence, the scores on the assessment are the lowest, marked in red in Table 15.

Scenarios 4, 6, 7 and 8 also partially allow for some years of education. These scenarios show an improvement compared to scenarios 1, 2, 3 and 5, but still lean towards a limited level and quality of education, with the possibility of not completing secondary education (less than 9 years of schooling). The main difference with the previous scenarios (1, 2, 3 and 5) lies in the degree of reflexivity of society. Society is evaluating the consequences of a deficient education system and is on the way to improving capacity building in a coordinated and institutionalized effort. However, the results are still in the process of improvement. Consequently, the middle scores (color yellow in Table 15), are assigned to these scenarios in the sustainability assessment.

9.7.6 Rule 8: Society's ability to govern (steering ability)

Following criteria are analyzed to assess this rule: *H. Governance uncertainties, I. Governmental policies for integrated energy system* and *P. Legal System.*

H. Governance uncertainties

The society in Mixteca has its own local dynamics that, once well-articulated, could promote adequate coordination between local governance and its population. This would provide autonomy and a certain degree of independence to autonomous solutions adapted to their own potential. To reach its potential, the society requires an appropriate capacity to react to the interactions within its population, as well as to external - state and federal - levels.

The results from governmental decisions in scenarios 1, 2, 3 and 5 in Table 15 appear to be discordant with expectations of wellbeing in the rural area. Despite the population expressing its dissatisfaction about the government's actions, uncertainties regarding course adjustment seem to prevail. There is a perceived lack of steering ability by the civil society that could result in the stagnation of development in the area. That being the case, the low grading in the assessment is indicated in color red in Table 15.

Whereas, in scenarios 4, 6, 7 and 8, the civil society could have increased its surveillance capability and reached a level of understanding of the multiple factors interrelated in Mixteca's overall system interactions. Results of the government's decisions could have been evaluated and pointed out for improvement, hence an increased satisfaction in the level of governance. Communities’ close relationship with the government could make it possible to exert the required pressure to drive the government's decisions to adjust to real-life challenges and develop further to improve the collective livelihood. Due to meeting the sustainability target, high scores are provided (color green in Table 15).

I. Governmental policies for integrated energy system

Energy policies encompass several spheres of policy that interrelate in a cross-sectoral landscape as economic, environmental, security and social policies. Therefore, society should be able to handle this realm and provide suitable direction into a future development. Mixteca requires the confidence to handle governmental policies at a local level, by exerting its own direction, given that the local system cannot be controlled from the outside - national level - it should be effectively handled from the inside. Mixteca should also be capable to competently integrate regulations to promote an energy system by understanding the relationship of this system and the environment in a cooperative synergy, rather than a subordinate relationship where both parts are interconnected at the same win-win level.

The pace of change in the area should be led by suitable policies. Energy policies have the power to carry out investments needed for energy transition, and private developers and consumers respond to these signals – policies - set by the government. Effective renewable energy policies across the energy sector could engage local communities in a social commitment towards their region and drive the local area into its own goals in a resilient future. Adequate *I. Governmental policies for integrated energy system* could provide the framework that enhances / promotes cooperation within other regions, increases competitiveness between states, sets targets, and provides measures.

The scenarios 1, 2, 3 and 5 in Table 15 would be highly likely to show that governmental policies are not aligned to long-term pathways, where future development in the region could be jeopardized by the lack of a robust system that prioritizes fossil fuels use above renewable energies. On that account, a decrease in solar energy generation will prevail. The inability to understand the consequences of the energy system in its relationship with the environment and social impacts could show a lack of steering ability to act and react to local-national challenges. Thereupon the low scores in the evaluation, shown in color red in Table 15.

Whereas, scenarios 4, 6, 7 and 8 are inclined to governmental policies which could have focused on future benefits, hence the support for solar energy could be aligned with present and future needs. The possibility of change to improve conditions might be the result of a thorough understanding of the system dynamic and interaction with the multiple actors and the environment. The national government, together with the local government, could have developed the ability to steer the path, creating adequate policies to optimize resources without jeopardizing a sustainable transformation. On that account, a future inclined to meet its present goals has a high evaluation (color green in Table 15).

P. Legal System

An appropriate legal system in Mixteca (and the rest of the country) should offer justice, security, an open government capable of ensuring fundamental rights, an absence of corruption and the capacity to ensure the rule of law. These aspects are relevant to sustainable development. The legal system should also be effective, and the population needs to feel confident in the local authorities' ability to guide the future of the region with suitable decisions. A fair and well-functioning legal system promotes human rights, contextualizes measures to effectively prevent conflict and encourages growth in the local area. Local governance itself is also accountable to laws and should guide its actions towards the protection of human rights and rule of law, as well as democracy as mutually reinforcing. Hence, the participation of society assists in strengthening the institutions which builds trust and promotes social cohesion.

The scenarios 1, 2, 3 and 5 in Table 15 are likely to disclose a worsening of the legal system which seems not to meet the justice demands of the communities. The steering ability of the legal system could fail to drive the communities to an improvement; decisions taken seem to have negative effects on multiple contexts affecting the environment, political, societal and economic dimensions; corruption levels could probably increase, undermining the region’s development in addition to promoting inequity and prolonging poverty. Consequently, missing the target for future sustainability, the lowest scores are given in the evaluation (color red in Table 15).

Alternatively, the set of scenarios 4, 6, 7 and 8 could foresee a strong citizen-oriented legal system that could make use of its capabilities to drive justice needs in line with the demands of the community in different contexts for the welfare of the collectivity in Mixteca. The control capability of the legal system in the region could significantly reduce levels of corruption, providing impartiality and a supportive legal foundation for development in the area. A significant reduction of corruption levels in Mixteca would help promote a basis for progress and sustainability. Hence, meeting its target and scoring high in the assessment (color green in Table 15).

9.7.7 Rule 9: Society's ability of self-organization

Two criteria assess this rule: *F. Population acceptance of renewable energy plans and participation* and *T. Community organization.*

F. Population acceptance of renewable energy plans and participation

Population cooperation has proven effective in providing start-up capital to establish new employment-generating activities in local communities, as well as to promote the creation of new jobs and an even distribution of revenue among those who generate it. Thus, population participation promotes acceptance and encourages promotion in the energy transition process. The self-organization ability of the society in Mixteca should be represented in strategies that promote local participatory forms of decision-making and voluntary commitments. Strategies should be designed and developed according to local circumstances rather than being imposed by national external control: the attempt should be made to coordinate different strategies of action, and experience exchange by allowing and promoting the active involvement of the population. The proposal is to monitor the quantity of local energy projects, either proposed or to be implemented. The target is that the community can organize themselves to implement one project per municipality. If no projects are proposed, a lack of perspective regarding a commitment to a sustainable transition will bring an unsustainable future.

Scenarios 1, 2, 3, 5 and 6 in Table 15 conceive that rural communities could accept and support renewable energy schemes, if the existence of temporary or scarce local solar energy projects could offer the conditions to participate in the decision-making process of such projects. Nevertheless, a resilient self-organizing structure would be required so that enduring projects could be part of the future development of the communities. As these scenarios partially meet the sustainable goal, an intermediate assessment score is indicated (color yellow in Table 15).

Scenarios 4, 7 and 8 envision that the self-organization structure of the rural communities could be useful in promoting the acceptance and free participation of all members of society in renewable energy projects. This structured unit could evolve over time according to the needs of the area, thus, it could be likely to respond to a desire for growth and development, producing a resilient pattern. For this reason, the highest points are given in the evaluation (color green in Table 15).

T. Community organization

The population's ability to participate in the development process of its community allows the inhabitants to make informed decisions concerning their needs and the future of the society. The ability of the society to organize can and should turn into an institutional direction and build confidence to participate in the development process, leading to uplifting outcomes such as poverty reduction. Society´s capacity of self-organization promotes community resilience, a quality that allows one to withstand, adapt to and recover from adversity; no wonder Mixteca has suffered from poverty for decades.

The population's motivation to participate in steering the community´s future involves a commitment to actively engage in diverse participatory processes such as community projects. These joint projects help build confidence among their members, commitment to a common goal, awareness about the current status and aiming for better wellbeing; Community projects help build leadership, organizing skills and accountability to carry the project to a satisfactory end. They also contribute to social cohesion, mainly when they succeed in involving disadvantaged groups – disabled people, women, native population, youth, or the less educated- A suitable target could aim to actively hold one project per municipality. Hence an indicator to measure *T. Community organization* could be the number of community projects aimed to uplift the community´s wellbeing, since it is only through adequate community organization that a society can fulfill its goals towards development and sustainability. Self-awareness and actions about their future collective needs provide a path to sustainability.

All scenarios in Table 15, except number 8, suggest scarce community projects aimed at the collective productive benefit, where the limited participation of some members of the community could be granted the opportunity to express their preferences and judgments. Not all participants might be recognized as actors of change, thus, slow development of the society could be expected. The community's self-organization should not only include political or social decisions but productive associations for a collective economic benefit. Since more efforts are needed, but improvements have been made in reference to the status quo, an intermediate score is given in the assessment (color yellow in Table 15).

Scenario 8 appears to promote the empowerment of each community member through a participatory process, allowing them to express their preferences and judgments and be recognized as agents of change. Active participation is essential for the further development of society, and the community's self-organization should encompass not only political and social decisions, but also productive associations for collective economic benefit. By maintaining a single community project on a steady basis, this scenario scores highly in terms of sustainability (color green in Table 15).

9.7.8 Rule 10: Balance of power between societal actors

The interplay of different actors that converge in a cooperative problem-solving arrangement to deal with various issues can provide organizational structures within a society aiming to implement programs with successful outcomes. Therefore, criterion *M. Cooperation between government, private investors, NGOs* address the rule *Balance of power between societal actors*. This interrelationship among diverse actors can contribute to a shared path of common work, bridging the rights and responsibilities of all parties involved in an environment of freedom and justice within a just distribution of power. The framework conditions are very important and should be aligned in such a way that the participant actors can have equal access to information, participation and decision-making. It is essential for civil society actors to participate so that cooperative action can effectively take place, thus balancing appropriately the power among the societal stakeholders involved in the decision-making process.

Scenarios 1, 2, 3 and 5 in Table 15 expose a weak legal framework that could discourage an appropriate balance of power between the societal actors: local government, private investors and NGOs restricting access to resources, given their inability to get a common agreement or a suitable path to follow. As a consequence, there is a lack of loans to promote productive activities; strategies resulting from unclear involvement in participation processes might not create adequate conditions for future development in the area. Goals might not be clearly defined or might not be aligned to the reality, favoring partially interested parties instead of the welfare of the communities. Consequently, these scenarios are likely to miss the sustainability target, which is reason why the lowest scores are assigned in the assessment (color red in Table 15).

In contrast, scenarios 4, 6, 7 and 8 suggest a strong legal framework that seems to provide an effective balance of power between the different involved societal actors, namely local government, private investors and NGOs, in which cooperative strategies call for a structured participation and decision-making process. The amount of loans for productive activities is likely to increase, enabling the integration of society in Mixteca in a sustained and stable structure. This implies that the involved actors have open access to all forms of information, consultation and decision-making strategies, and consequently a sense of stability along the dynamic process, with the promotion of symmetrical communication between the societal actors. Adequate future perspectives might be foreseen, thus, high scores in the evaluation are shown, in green color in Table 15.

9.8 Summary of the instrumental rules assessment

Figure 34 below shows the graphical representation of the instrumental rules assessment. Future pathways for Mixteca, as explained in sections 8.3 and 8.4, show two divergent patterns; one promising and the other one pessimistic. Nevertheless, among both sets of scenarios (Cluster 1 and Cluster 2 as identified in section 8.2), some specific criteria stand out, providing some hints of an emerging understanding of sustainability, even within Cluster 1. The particular case of the rule, *Society's ability of self-organization*, can be seen in Figure 34 as the highest scoring rule. This is due to the two criteria associated to it: *T. Community organization* and *F. Population acceptance of renewable energy plans and participation*. Both criteria show a promising performance in the future outlook - although it is not optimal on the path to a considerable improvement. These outcomes confirm that local participatory processes are crucial for the implementation of renewable energy projects, because the acceptance of the project by the inhabitants facilitates its deployment (Del Río and Burguillo, 2008).

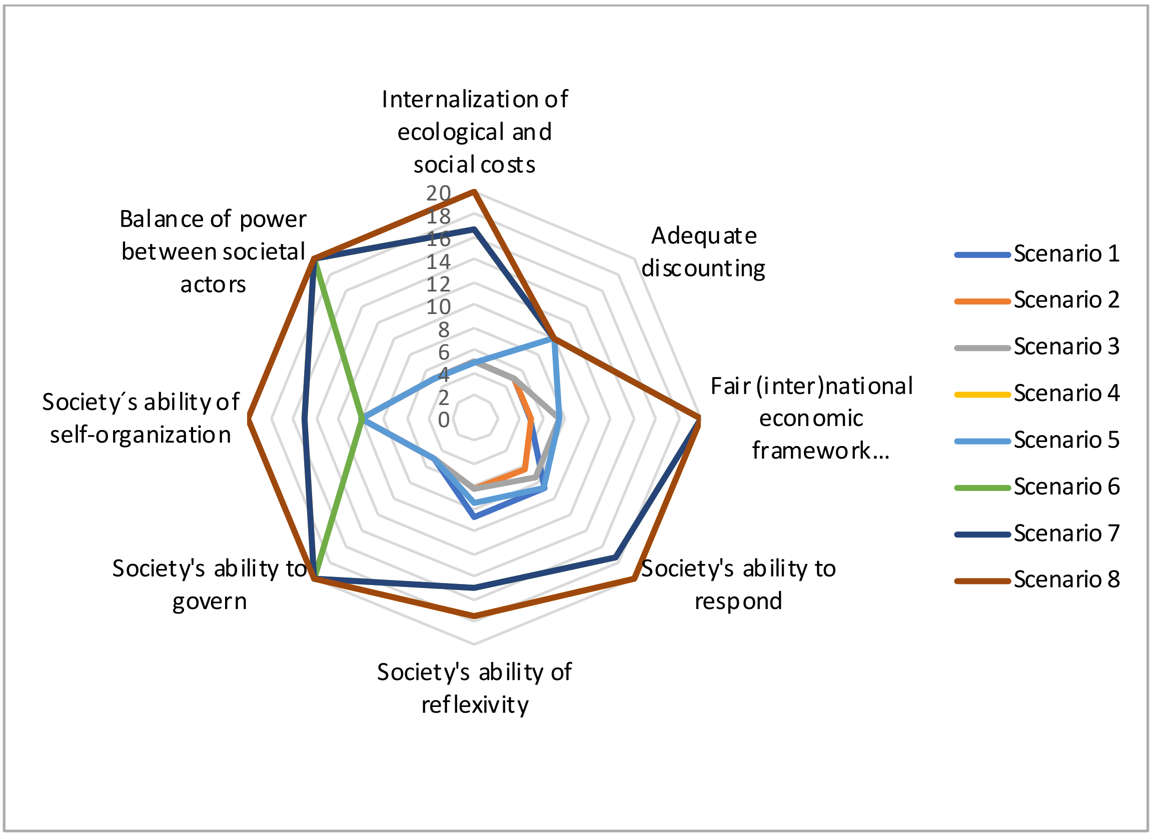


Figure 34. Graphical representation of ICoS instrumental rules assessment.

Another rule that partially shows hints of favorable future conditions is *Society's ability of reflexivity*, whose improvement is mainly driven by the criterion *B. Ethnic identification*; hints of maturity in a society that values its roots, customs, traditions and cares about the cultural value of native groups by promoting their native languages and increasing the number of speakers so that future generations can experience the knowledge first-hand. Mainly due to these two interrelated scores, the two cluster patterns in Figure 34 are not as clearly identified as those in Figure 32.

The assessment of the rest of the instrumental rules follows the contrasting pattern between the two clusters: Cluster 2 is (mostly) under the sustainable pathway, while Cluster 1 not. This means that the assessment of these instrumental rules concerns the way to meet the substantial rules addressed in section 9.7. This means that the assessment of the instrumental rules can identify the institutional, political and economic framework conditions that need to be in place in order that sustainable development can effectively take place.

An overview summary could be depicted as follows: in Cluster 1, with the exception of *the society's ability of self-organization* and partially *society's ability of reflexivity*, Mixteca society does not have a clear understanding of, or is not prepared to advance in, a sustainable future, since the structural conditions are not mature enough. Unsatisfactory performance is led by the ability to govern, which is consistent with the status quo, in which governance uncertainties, a weakened legal system characterized by, (almost) non-existent rule of law and lack of enforcement of policies - in this case supporting renewable energies - have halted the *sustainable use of renewable resources*, by not promoting investments in renewable energy, and by allowing impacts on the environment and population Ecological and social costs will continue to be unrecognized and underestimated, hence a lack of access to basic services is still a future scenario; climate change impacts will continue in the future if no measures are taken in the present; and no added value can be brought from non-existent investments on RE sources in the area. Job and earnings conditions in the area will not improve compared to the status quo. The reflexivity ability needs to be strengthened to change course and not be limited to ethnic recognition; women's empowerment is also underrated.

In contrast, Cluster 2 provides an apparent framework that could lead us to think the path for a sustainable future is on the right track. The description of scenarios in Cluster 2 can help us answer the second part of the second research question: "What could a sustainable future look like, and how could Mixteca achieve it?" (see chapter 0). The rule *Society's ability of self-organization* is fulfilled partially only under scenario 8; the rest of the scenarios of this cluster 2, scenarios 4, 6 and 7 (and even scenarios 1, 2, 3 and 5 of Cluster 1) show similar performance for this specific rule: a path of sustainability into the future. Although most of the remaining rules show a positive trend, the lacks in fulfilling all rules might be explained by the fact that society is not completely matured, sustainability is a hard concept to grasp and a drastic change of current conditions is needed in the present to succeed in the future. It might also mean that 30 years lapse is not enough for Mixteca. From the 4 scenarios of Cluster 2, the only one that is nearly completely sustainable is scenario 8. Still, some work needs to be done; the rule *Adequate discounting* is the common weakest link in all scenarios to pave the way into a sustainability framework.

"The challenge now is to ensure economic development eradicates poverty, while reducing inequality and promoting environmental sustainability

— Kofi Annan (2013)

10. Transferability of the findings

This chapter 0 and following chapter 0 conform Part 5, the last part of the dissertation (see chapter 1).

As discussed throughout this study, achieving sustainability is a current and central topic of global social, political and scientific discussion (United Nations, 2022; Sachs et al., 2019; Patterson et al., 2017; Loorbach et al., 2017; Renn et al., 2012; Lafferty and Meadowcroft, 2000). The *Scenario-based sustainability assessment model* (chapter 0) intends to fill the gap in the complexity and subjectivity of diverse methods of assessment by providing general guidelines that can be adapted to context-specific locations. The assessment process and context features are important because they can improve the effectiveness of assessments (Hacking and Guthrie, 2008).

One option to achieve faster progress towards the global goal of sustainability could be to identify and analyze the effective components of successful cases of renewable energy transitions, so that these components could be adapted and replicated in other contexts, e.g. grassroots initiative programs (Biswas et al., 2021a; Smith et al., 2015). Nevertheless, context conditions are a key driver for adaptation and success. General abstractions can be identified from overall country-specific conditions, even though there are differences among countries. For instance, Latin American countries in general show a commitment to fight against poverty and look forward to sustainable development promotion (Dane and Perticará, 2013); but their policy responses score poorly given weak political institutions and unstable governance (Transparency International, 2022). Common framework conditions could be identified, e.g., population vulnerability, weak legal system - corruption -, low economic incentives for sustainable projects, poverty, etc. But there is no general template or standard, rather, there are common framework conditions that are suggested and then need to be adapted to each region and context. The global aim is to scale the local positive outcomes towards a general sustainability, identify the barriers in a holistic way, and leave no-one behind (United Nations Development Programme, 2018).

The *Scenario-based sustainability assessment* performed in this study goes beyond an analytic perspective; through the definition of goals and procedures, the integration of the CIB and ICoS approaches entails a normative stance. This integration outlines a framework design with a detailed and specific context which is embedded in a general focus. Critics of the general context approaches focus on a lack of inclusion of specific characteristics or issues inherent to local contexts (Morse and Fraser, 2005), while context-specific approaches are seen to reduce the possibilities of standardization among different systems (Binder et al., 2010). Consequently, it could be argued that the use of context-specific approaches could see a limitation of transferability among different places (systems); in addition, these could also be more time consuming to develop due to the specific context analysis required. While this may be so, *Scenario-based sustainability* *assessment* is a structured approach whose transferability can be identified in various aspects. Based on ideas of transdisciplinary research (Wuelser et al., 2021) and taking the current study as reference, transferability is proposed to take place as follows:

- **Method**: the *Scenario-based sustainability assessment* approach used in this work.
- **Framing**: the definition and description of the system, reflecting on specific perspectives, boundaries, and aspects considered; these might not necessarily be context-specific.
- **Interconnections**: overall fundamental relationships among components of the system, i.e., states and interdependencies. Might be case-specific or topic oriented.
- **General outcomes**: solution proposed based on technology, non-specific fundamental arguments, learning, concepts, values, how the study was conducted.
- **Insights, data**: case specifics, research results and outputs.
- **Application**: the motivation of poverty alleviation through the (renewable) energy transition as well as the perspective regarding the social value of energy.
- **Practical knowledge**: from research to practice, the implementation of the study case.

Method: The application of the *Scenario-based sustainability assessment* model (see chapter 0) is a comprehensive and systematic approach that can be adapted to specific circumstances and cases due to provision of procedural and sequential guidance, which is useful in transdisciplinary processes. The application of the ICoS and CIB, the two mature and well-developed approaches that are integrated in the model, has been documented in diverse research fields, where they have been transferred separately with proven success to different contexts and circumstances, (see sections 5.1 and 5.2). The integration of both approaches in the *Scenario-based sustainability assessment* model aims to assess a sustainable future based on scenarios in a comprehensive way. The systematic procedure allows a step-by-step process with guidance on how to derive the scenario assessment and adapt it to different contexts. Mainstreaming a *Scenario-based sustainability assessment model* should aim to be applied similarly to ICoS and CIB. The method can be adapted to qualitative as well as quantitative data in the same systematic procedure, taking into consideration societal aspects and their interactions shaping the energy transition.

Framing: Describing problems or circumstances which define the system from different perspectives helps to provide a structured outline to the system (descriptors / criteria). The transferability of the framing intends to be non-specific but copes with the procedural aspect of the method by providing general guidance on how the process can be designed by incorporating the interdisciplinary circumstances -cultural, political, environmental, societal, technologic, economic, etc., - to be considered for an appropriate framing (see chapter 0). In addition to the non-specific framing process, a variation could include the structured interdisciplinary boundaries per se; these could also be subjects of transferability under certain circumstances, i.e., in regions with comparable conditions, or with similar needs, or as a reference basis for other corresponding cases. These descriptors / criteria could still be general descriptions of a specific discipline which might be related to the case of study or to any other system. The criteria and its states could be replicated to other cases where conditions are similar to the study case, for example, within the same country. Some indicators are generally recognized globally, e.g., air emissions (World Health Organization, 2006), women's employment rate (World Bank Enterprise Surveys, 2022), emigration rate (World Bank, 2022). The general framing can be comparatively transferred to other cases and contexts, while specifics framings are less flexible to be transferred.

Interconnections: This relates to the impact relationships between the states of the descriptors. This linkage represents a specific level of relationship between the general and site-specific perspectives that might not be completely transferable, unless identical boundary descriptors and interrelationships apply to the new case under the same conditions, which is unlikely to happen. Otherwise, the new linkages would need to be judged and assessed by the experts in the scenario analysis and new degrees of influence assigned accordingly (see section 5.2). The context-specific analytical procedure provides information on how certain aspects relate to each other, as in the states and interdependencies addressed within the CIB context (see section 8.1), as well as the indicators and possibly the targets (see section 7.4) in the adaptation to the assessment. These specifics could be useful as reference case or as an indication for further research.

General Outcomes: Beyond the specifics of the problem being tackled, the way it was tackled is relevant to transfer to any complex societal problem. The strategy used to address the challenges encountered during the research can be used and adapted to other contexts and situations. The transdisciplinary approach to integrate views and apply them to the research and learning process also contributes to the general outcomes that can be considered transferable (Adler et al., 2018). The *Scenario-based sustainability assessment model* is not restricted to a specific technology, which would impede its transferability, and the approach could be used for any type of technology by defining the relevant criteria.

Insights, data: Information and concrete research results encompass both case- and context-specific outputs that could be transferred to some extent and under particular conditions. In this study, for instance, the main drivers, the active and passive descriptors, the scenarios identified, and the sustainability degree of each scenario are concrete and context-specific results bound to specific circumstances provided by the system boundaries (see chapters 0 and 0), and their transferability is limited for use in a new case. For this type of information, transferability has to address the comparability of the two cases (reference case and new case) and the two contexts.

Application: The motivation to use the renewable energy transition as a means to poverty alleviation can be transferred to other regions and cases and adapted to different types of (renewable) energy transition: solar, wind, biomass. Different types of projects can be created depending on the most suitable resource(s) in the region or system adaptations. The perspective to use the social value of energy as a framework can also be transferred to other circumstances, geographic locations and cases.

Practical knowledge: the implementation of the research into practical action is highly desirable for transferability of knowledge that involves transdisciplinary and interdisciplinary collaboration between multiple stakeholders (government, society, NGOs) through different forms of dissemination so that research can be useful to solve a societal problem in a practical way. This is the ultimate degree of transferability, since the research intends to tackle issues and needs from the perspective of those involved by providing them with scientific knowledge (approach, technology, how to implement) as potential means to address the societal problem. It is the most demanding transferability aspect because it intends to remedy real-life issues and challenges.

The design of social learning to advance the goals of transdisciplinary methods for sustainability transitions features co-creation processes and aims to maximize the uptake not only of research findings, but also of the principles and values underlying collaborative action (Biswas and Miller, 2022b). The transformative effect could be to reorient mindsets toward research and value-based processes that overcome knowledge lock-ins and power imbalances. The effect could also be to build capabilities and reflexive action derived from evidence-based cases. This reflexive engagement with knowledge would avoid the common challenges observed in energy transitions as Biswas and Miller suggest, and would promote transdisciplinary collaboration in the knowledge building process facilitating knowledge to action pathways.

Illustration of transferability in Mixteca study

As highlighted in chapter 0, this study focuses on a section of the region known as Mixteca which is located in the state of Puebla. To date, most of research and attention has been focused on the Mixteca regions which lie in the poor neighboring states of Guerrero and Oaxaca, with Oaxaca being a well-known destination for NGO interventions and federal funding due to its high rates of extreme poverty (21% from Oaxaca vs 13% in Puebla) (CONEVAL, 2020). Given that Mixteca is a region shared among these three states, it is possible that the outcomes of this research could be transferred within these two neighboring states. The following paragraphs provide insights as to how transferability could take place, taking this study as the base case.

The transferability of the method is feasible, as it is not context-specific, but provides the conceptual and normative background that facilitates addressing the interaction of complex societal systems by exploring potential futures in a more comprehensive sustainable assessment of scenarios. The approach it is not limited to a geographic or spatial area; it can be useful to assess the sustainability of future scenarios within the framework conditions that require local adaptation according to the specific context. Through this method a procedure can be described to identify and assess drivers of technology adoption, and assess the sustainability of future plausible scenarios. The systematic description of the process facilitates the design, adaptation and application of the procedure in different contexts, and is not only limited to an energy transition, i.e., technology for renewable sources. It could also be applied to other system changes, e.g., the introduction of a nexus system (water, energy, resources, waste). In summary, transferability of the *Scenario-based sustainability assessment* method is possible across geographic conditions and disciplines.

The general framing can also be transferred across cases and circumstances, since the system boundaries and perspectives could be adapted as nonspecific scopes which provide a systematic description of the system, i.e., the general aspects and disciplines that constitute the framework: environmental, economic, societal, political, cultural, technological as. Once these are selected, specifics about geographic or spatial locations should be cautiously considered. In this case, the Mixteca region in Oaxaca and Guerrero states should receive special attention regarding the spatial and geographic conditions, since the Mixteca region is close to the sea in these two states, hence radiation levels and humidity may vary and alter outcomes.

The interconnections between descriptors are unlikely to be transferable in their entirety since these represent a specific level of relationship given by the context conditions of the area. For the wider Mixteca (3 states) region, these may need to be reevaluated, especially those related to ethnicity, because other ethnic groups reside in the wider region, hence customs and traditions must be understood. If ethnicity should be evaluated within an urban context, this factor is usually a discriminatory towards native people (neglect of services, being disrespect or abuse); hence, rather than being a condition related to a pride adaptation or neutral identification, this could be taken as a negative characteristic from a defining starting point. This judgment affects the interconnection with the other descriptors linked to it, such as *G. Job and earnings, O. Financial market in rural economy, S. Women's empowerment* and *T. Community organization,* in our reference case.

General outcomes might be transferred. Mainly this would refer to the way the research was conducted, the interdisciplinary aspects considered, the technology suggested and the way the societal problem was addressed. As far as the technological aspect is concerned, this study case was developed considering geographic and topographic conditions for which irradiation levels and capability of the population to install solar PV modules is proposed. The analysis in other regions should consider the physical locations for suitability for the proposed technology. In this sense, rural regions in the south of Mexico with high wind resources, could benefit from this type of analysis; especially, given that in the past decades, social aspects were not integrated into the design of the energy systems, and consequently the social opposition to renewable energy projects was the biggest drawback to an incipient renewable energy transition (Martinez, 2020).

The insights and specific data obtained in this study may serve as a reference guide, since these are context- and case-specific, and may not apply completely to the rest of Mixteca. However, they could assist in providing indications and directions that could shape the success or bring to attention drawbacks of the energy transition process. The judgment of the interconnections among descriptors would need to be re-evaluated, since they are the base that support the achievement of the sustainability targets of the assessment.

The motivation of overcoming poverty through the solar energy transition is a valid argument to pursue across geographic conditions, and is not necessarily solar technology-related. The main aim of overcoming poverty through the energy transition could be applied to other technologies or systems. For the Mixteca region in the neighboring states, given the main two conditions in the area: high degree of poverty and a scarce means of economic activity under a high solar radiation region, the same aim as the current study case can easily be transferred.

The final aspect of transferability, called in this study 'practical knowledge', is the ultimate stage of transferability and relates to the implementation of the research. This could take place once the research study pertaining to the new case is completed. This transferability is case- and context-specific, and is highly unlikely without previous re-evaluation and adaptation of boundaries conditions, definition of descriptors / criteria, their states and interconnections, judgments. Transferable knowledge from the research study would be relevant for further progress in sustainable development and problem-solving. This next stage would consider the implementation of the research outcomes, to tackle the problem in a practical context.

"It is technological innovation that has been insufficiently tuned to the challenges of poverty alleviation, human rights, social justice, and human wellbeing"

— Westley et al. (2011)

11. Paving the path to a better future

In the quest to alleviate poverty in Mixteca, a solar PV energy system in the region could be implemented to trigger an energy system transformation by tailoring the interrelated societal aspects. Most previous research on rural development in the region or within the country's context, has focused on economic initiatives or programs helping inhabitants to tackle income poverty (see section 2.1.1). But comprehensive research involving an energy system transformation which considers the social value of energy is a more suitable approach to ensuring a sustainable future while reducing poverty, and at the same time lifting people's capabilities to create collective wellbeing by integrating the societal aspects as the drivers of change.

The following sections provide some final observations regarding the considerations involved in the application of the ICoS sustainability concept used for Mixteca (section 11.1). This is followed by a concluding discussion (section 11.2) where three aspects are articulated: the societal factors and governance as drivers of change; the challenges identified in the application of the *Scenario-based sustainability assessment* approach in this study; and concluding remarks on the application of the approach in Mixteca. The chapter ends with the outlook for future research (section 11.3). This chapter 0 and previous chapter 0 conform the last part of the dissertation (Part 5), see chapter 1.

11.1 Challenges and considerations for the sustainable approach in Mixteca

Mixteca is a poverty-ridden region, where adapting the three main sustainability goals applied in this research requires effort. An important challenge is that the intangible value of each of the main goals is not visualized nor appreciated in the region. Some elements of them are valued by native communities, but the current institutional framework is not aligned with the practice. Human existence in the region is threatened, and it might be that the value of life (human and the environment itself) is underestimated and undervalued since the most basic need in Mixteca is for survival. The first challenge would be to create awareness of sustainability (and its goals / benefits) at all levels: among the population as well as within the corresponding system, local authorities, and at state and national levels. Local institutions have the challenge to bring attention to the area so that practices that threaten the life of the population and ecosystem can be controlled; e.g., licenses to (ab)use land by factories or discharge emissions and polluted water in the area need to be monitored to safeguard human life, flora and fauna in the region.

Uncoordinated efforts or activities result in the imbalance of priorities among goals. While ICoS assigns the same priority (see section 5.1) to its three goals to reach the integrative perspective of sustainability: *Securing human existence, Maintaining society's productive potential,* and *Preserving society's options for development and action*, it is a challenge for Mixteca to find such a balance. It might need to start its focus on *Securing human existence* as a priority (which is not stipulated under the ICoS rules) because for instance, investments or *M. Cooperation between government, private investors and NGOs* cannot take place if there is not enough income or jobs to sustain those endeavors.

Mixteca's concern for survival and *Securing human existence* is focused on the present. Planning for the distant future is another degree of complexity that is beyond current understanding. This may be the reason why the interconnections among the other two sustainability goals (*Maintaining society's productive potential,* and *Preserving society's options for development and action*) is not straightforward in Mixteca. The lack of awareness is also related to the lack of vision on collective wellbeing. Each of the inhabitants is immersed in securing their own existence and loses sight of the community welfare. Consequently, a missing connection between actions and responses fails to integrate a sustainable chain reaction in the present and into the future.

The local sustainable actions in Mixteca need specific goals, most likely society-driven decisions that push political and economic will towards development challenges, such as education, basic services, health and equality of opportunities. The main aim should be alleviating poverty in all its forms in a sustainable way.

A major challenge is the lack of consciousness regarding sustainability, but this does not mean people do not care about measures toward sustainability, or that their actions do not reflect a sustainable performance (although, partially, some do not). Mixteca cultural heritage has shown respect for and integration with the ecological system, a living unit entity in which humans are embedded (see section 7.3.4). Some "sustainability knowledge" has allowed the population to guide their actions empirically, nevertheless, a formulated plan of action is required to appropriately carry the region into a sustainable future.

The provision of basic needs is the top priority for the population - access to health services, education, water, energy provision, food provision and housing. Nevertheless, special attention should be paid to access to quality goods and services. It is not enough to install a school if the quality of the education is poor, or if it is discriminatory to the sector of the population who do not speak the predominant (Spanish) language. Safe, drinkable water provision should reach every household, and long walks from home should not be necessary. A suitable wastewater treatment facility should also be designed or integrated as part of a water recovery system. Access to such safe water facilities would help avoid the risks of disease and life-threatening illnesses. Costs associated with these health conditions would diminish. A better quality of life could be expected for children and the elderly. As a result, the social costs associated with care for these groups could decrease. Households should have suitable housing materials (roof, floor and walls) and be located outside risk areas, i.e., away from riverbanks, cliffs, ravines. It is common for people who are not entitled to a piece of land to locate "provisional" houses in these risk areas, thus endangering their lives. Energy provision should aim to come from clean renewable sources, and use the rich solar resources. It should also have the reliability and stability to be used for productive activities. The current use of energy for household activities is restricted due to the bad quality of the housing materials and high prices. Hence, biomass, charcoal or wood are still the chosen alternative for cooking fuel. The main challenge to basic services is not limited to provision, but to their quality within a sustainable context.

The informal economy which currently represents more than half of the economic market is an issue that requires sustainable adaptation. As long as better income opportunities are foreseen and available to vulnerable groups - women, elderly, native communities - the share of informal labor should decrease. The need to develop a productive activity voluntarily should be a sustainability target that would benefit the wellbeing of the population and would also help decrease rates of emigration.

The combination of the fact that Mixteca and the whole region possesses insufficient awareness about the future, and low participation by the main actors, has caused structural barriers which hinder actions towards sustainability: either a lack of knowledge pro-environmental sustainability, a lack of resources or opportunities for participation and co-decision-making so that actors can effectively contribute their sustainability impulses to the political discourse.

Natural capital - the natural resources that the ecological system generates - is often the only significant material goods that inhabitants in poverty-stricken regions such as Mixteca have access to. They could provide economic capital for development and a stepping-stone beyond mere subsistence. In regions such as Mixteca where the ecosystems are degraded, this limits their potential as a source of environmental income. Community efforts to improve or restore the land's potential could prove beneficial to income-generating activities. This activity could spotlight an appreciation of the land as an economic asset, providing an incentive for long-term care of the ecological system, thus fulfilling several ICoS sustainability rules: as an opportunity for *autonomous subsistence based on income from own work*, *sustainable use of renewable resources*, *society's ability of reflexivity and self-organization*.

If there is not a behavioral change among people for restoration / maintenance of degraded landscapes and ecosystems, then future generations could be impacted by a lack of opportunities to benefit from natural resources in the same way as present generations. This change should be supported by adequate policies, education and knowledge dissemination. There is also a need to strengthen collaboration among the different actors and institutions (government, NGOs, private sector) so that efficient use of resources is promoted, with suitable allocation among those who need them most.

The main difference between the sustainability concept in high-income countries and low- and middle-income countries is that in high-income settings civil society has already some degree of empowerment and their basic needs are covered. The majority of the population in Mixteca is struggling to survive. The fight is to gain basic rights, basic services, and obtain minimum recognition as individuals. NGOs along with governmental institutions and private investors should be first committed to providing basic needs to Mixteca. ICoS does not assign priorities to any of the three general goals, but given the poor conditions in Mixteca, the general goal of *Securing human existence* is foundational to sustainability in the area. But this is not enough alone; if the other two goals are not implemented at the same time, it will not be possible to either maintain the society's productive potential or to preserve it for future development and action. Inhabitants are currently not concerned about sustainability when their existence is not secure, hence, as long as they can gain access to services and resources, it becomes irrelevant where these come from.

Through specific goals, commitments could be created at government, organizational, community and individual levels. Institutional efforts from all stakeholders and interested parties should focus on implementing a plan of action to fulfill the proposed sustainability goals through effective problem solving, decision-making and suitable implementation of strategies. The fight against poverty involves a multi-stakeholder action perspective, effort and engagement across the population, private investors, government at all levels, the research community and NGOs.

Decisions and actions should be implemented in the present so that outcomes can be obtained in the future.

Concerns are mostly addressed to solve current deficits, and a direction that steers efforts to future issues is missing. A participatory structure exists, and a creative environment provides the context for improvement. A well-organized society can be an informed society that can support transformation, i.e., an energy system transformation, through understanding and teamwork for the benefit and success of the whole community. Cultivating a “learning organization” will enhance aptitude for change, resulting in organizations that are well-positioned to navigate future challenges (Beerel, 2009).

Funding for project implementation or technology could be a challenging aspect, since banking loans are basically inaccessible as a single inhabitant of low-income. Nevertheless, the cooperative concept introduced in section 4.5 could be useful for the inhabitants of Mixteca to gain access to their own financing, as well as to own the assets and benefit from the gains (energy access, sales of electricity surplus). Renewable energy projects usually represent multiple benefits and might also bring a source of income generation on a long-term basis, thus investment should be worth it. Renewables are a new investment alternative in the area, offering a potential business model where consumers could become producers - prosumers or co-owners -, with earnings distributed locally (Lowitzsch and Hanke, 2019; Miller et al., 2022). It could also attract foreign investors who are willing to participate in the earnings from clean energy sources and become part of an “environmentally responsible industry”.

Suitable communication, information dissemination, and promotion of education are key activities that would raise awareness, and encourage support and involvement in a sustainable energy transition. It would also improve behavioral change towards new approaches and strategies to prioritize collective wellbeing rather than personal benefit (as current status quo). Changing individual behavior through education can only take place when everyone is able to assume their responsibilities; only then are the structural roots of inequality tackled and people are able to exert their rights (to income, housing, education, health, etc.). According to a World Bank Group report (Lakner et al., 2019), addressing inequality has a larger impact than increasing a country’s annual growth, which suggests that lowering inequality might be the most viable path to decreasing extreme poverty. This target is a major challenge under Mixteca’s conditions.

11.2 Concluding discussion

The final comments of this study are divided into three parts: a brief conclusion on the societal aspects and governance as drivers of change; final remarks on the *Scenario-based sustainability assessment method*; and a final discussion on the application of the method in Mixteca.

Societal aspects and governance as drivers of change

This study intends to contribute to a deeper understanding of the social interrelationships and implications emerging around an energy transition in rural communities in low-income countries whose aim is poverty alleviation. The contribution of the social value of energy to the community’s development and individual human development has been contemplated in this study from the two perspectives envisioned in the *Scenario-based sustainability assessment* results: one is sustainable provided by the scenarios 4, 6, 7 and 8 (Cluster 2) and the other is unsustainable identified as scenarios 1, 2, 3 and 5 (Cluster 1). These insights are valuable if we would like to develop sustainable energy systems that deliver social value and contribute to just human development while at the same time avoiding those which are unsustainable and unjust.

The identification of the driving forces plays a significant role in shaping the future scenarios for the local region, mainly through interplay with societal features. It was also useful to identify that societal impacts are a strong driver of energy system transformation. In Mixteca, it was shown that societal-related aspects which influence the well-being of the communities are more significant than the change of energy system. Nevertheless, if conducted appropriately and considering the societal impacts involved, the energy system transformation could be the means to uplift conditions (basic services, health provision, education), employment opportunities creation, and even wealth distribution in the area in the long term. Only when these benefits derived from energy systems outweigh the costs and risks, generating local value, ownership, and control over the energy network would the system be able to break the energy-poverty nexus (see section 2.1). Hence, the social value of energy is increased.

The strong and tight interrelationships between the socio dimensions in which Mixteca is immersed could be the reason why in the past isolated efforts directed at a single criterion to tackle poverty have not been successful. The challenge is to be able to see the complete picture holistically and to assimilate how all the interconnections will influence, to some extent, the outcomes of the actions pursued (see Figure 27 in section 8.1).

This case has proved useful to show that the social value of energy strengthens the societal drivers which allow the technological transformation to be triggered - under suitable conditions this could improve living standards and decrease poverty in rural Mixteca (see chapter 0). A challenge for the rural area is societal adaptability to the variable contextual conditions, and to the interdisciplinary exchange in the path to a transition. A critical reflexive evaluation of the outcome from the scenario evaluation could bridge the gap between the transition dynamics and the policies in the developing context. The supply of renewable energy will not necessarily bring sustainable development to the region, if the integrated features of the system are not considered; mainly the interrelated social aspects. If the transition can be kept open and focused on the goal of poverty alleviation, then innovation capacity could contribute to the societal upgrade. Providing energy access to alleviate poverty is more about understanding the importance of the social value of energy in the population’s daily activities and supporting them to improve their wellbeing, rather than a transfer of technology. This is an opportunity to make a shift in rural communities.

An identified key driver of energy transition and influence in this study is its governance (see chapter 0). The predecessor of the SDGs, the Millennium Development Goals (see section 2.1.1) pointed out that good governance at all levels is indispensable for creating a favorable environment for poverty alleviation and development; a prerequisite in guaranteeing universal values as human rights; and is the operational link between noble aspirations and effective realization (UNDP, 2004).

Political governance institutions (at national, state and local levels) hold the ability to promote social cohesion and integration, and ensure the wellbeing of the population; they are also responsible for the suitable inclusion of disadvantaged groups (poor, native communities, disabled…). Nevertheless, such inclusion is not always in the interests of those in government.

Local communities in Mixteca face the challenge to succeed despite the lack of support, mistrust, or the changing governance in the status quo (and possibly in the future). The unstable democracy and unreliable political condition in the country (Sánchez-Talanquer and Greene, 2021) linked to the local events have implications in the policy discourse and application. Hence, it is strongly suggested that local communities, along with NGOs, interconnected institutions and communities learn to work independently from the government and acquire the resilience needed to keep working towards the common goals of the inhabitants, despite the political arena - local or national. Two key aspects here are: the weak adherence to the rule of law including those in the government and leadership positions, and the corruption degree, where nepotism and strong personal relationships within the government are favored over a fair share in implementing development projects (Human Rights Watch, 2022). Governance should aim to provide the required framework conditions for research, investment and, financing, and influence the population to drive and shape a just and sustainable energy transition. Examples where rural communities have led the change in a cooperative and effective energy system transformation across Latin America, Africa and Asia (as referred in section 2.1.3, chapters 0 and 0) can be found in (Biswas et al., 2021a; Miller et al., 2022). Smith affirms that this type of bottom-up socio-political programs are more transformational, since the community's initiatives embody new ways of thinking and acting upon energy-related aspects (Smith et al., 2015).

An energy transition broadly involves a change in an energy system, traditionally to a particular fuel source or technology. The concept of energy transition requires systematic changes, as it addresses a spectrum of not only technology but also the broader political, environmental, economic, and above all, social assemblages that are built around energy production and consumption, which are currently directed towards sustainable development. Changes in the energy supply and the shift toward renewable energy resources cannot be comprehensively understood without considering the implications of the societal dimension. Given that developmental challenges like inequality and poverty are major challenges - even above the environmental and sustainable ones - in low-income countries and regions like Mixteca, the relationship between the energy system transformation and sustainable development should become the core focus of analysis in these countries. Quoting Westley et al.: "It is technological innovation that has been insufficiently tuned to the challenges of poverty alleviation, human rights, social justice, and human well-being" (Westley et al., 2011).

Scenario-based sustainability assessment: conceptual framework

The scientific aim of this study was the presentation of a consistent framework to comprehensively and systematically identify and assess the sustainability of future scenarios. It can be concluded that the integration of the two proposed approaches, ICoS and CIB, proved useful in this case as a model capable of identifying and assessing in a comprehensive and systematic way the sustainability of future scenarios. Moreover, the transferability of the diverse perspectives explored in chapter 0 allow for dissemination and replicability of the method itself, proceeding through the framing, the interconnections, application, and insights considering the particular circumstances and conditions described.

Some challenges for the application of the proposed method were identified through this study:

The selection of the descriptors / criteria for the *Scenario-based sustainability assessment* required an intensive articulation between the stakeholders to ensure that they were suitable and operational for both approaches. The complexity of the CIB matrix and the analysis of interrelationships can at specific points be a demanding task for the stakeholder analysis, thus restraining the quantity of descriptors, as well as the analysis of interrelationships - judgments. This could in part be compensated with the intuitive procedure in the sustainability assessment application.

The integration of both the ICoS and CIB approaches increases the complexity of the system under review, and may potentially lead to a reduction in transparency and traceability (quality criteria of scenarios, see section 2.3.2) of the findings.

Intensive engagement was required among the stakeholder groups in a first step to make the definition and interrelationship judgments, and in a second step, for the sustainability assessment. The current proposed method does not make a distinction between the designation of stakeholders for the descriptor judgments, and for the sustainability assessment. This could be an open point of discussion. For future operationalization, it is suggested to discuss a priori the designation of stakeholders to the definition of the descriptors / criteria, on their judgment, and on their assessment.

The shared and common boundaries of the system for CIB as well as for ICoS (see Figure 25) require that the stakeholders have a clear understanding about the process and its implications, i.e., about the definition of the descriptors / criteria, their states, indicators and targets. In cases where there are different type of stakeholders providing judgments, and others providing assessment, the functioning of the system should be clear, understandable and in line with the overall outcome. It might be also possible that conflict on the definition of indicators and targets exist among the stakeholders, leading to (non-)achievement, depending on the performance and measures used.

This study has highlighted how important it is to identify, operationalize and assess the social criteria, although it became challenging to determine appropriate indicators for measuring and tracking progress due to the lack of (reliable) data and / or traceability in the local context. Defining the targets of the social aspects, given the qualitative nature of the criteria, was also a demanding task. This aspect might also be a point of discussion between the stakeholders of the scenario definition and those in charge of the assessment (where these are different groups).

Scenario-based sustainability assessment could allow the sustainability role to be included within transdisciplinary collaboration and either enhance the participation of stakeholders and direct beneficiaries to develop strategies that link present decisions with a future desired sustainable scenario, or avoid undesired unsustainable scenarios, by addressing uncertainties to enable more informed decision-making. The holistic approach supports looking beyond one side of the transition, hence, stakeholders from diverse areas of expertise could contribute to developing strategies towards a general sustainable development. Consequently, this approach assists the promotion of transdisciplinary research.

Adoption of the integration of the *Scenario-based sustainability assessment* as method allows us to identify the sustainability opportunities in the future desired path, as well as the risks of an unsustainable future; additionally, it provides an overview of the (un)sustainable path to poverty alleviation. The practice of both approaches assists in facilitating targeted advice by assigning quality improvements in those criteria whose future risks a sustainable development under a certain path. This integration also shows to what extent the key sustainability aspects are addressed in the assessment. The *Scenario-based sustainability assessment* makes it possible to identify sustainable development opportunities by strengthening a sustainability-based approach in decision-making processes. The holistic approach of the *Scenario-based sustainability assessment* throughout this research suits the comprehensive analysis performed amidst the scenario array, where paths and strategies towards poverty reduction can be tailored.

Application of the Scenario-based sustainability assessment in Mixteca

Through the use of the *Scenario-based sustainability assessment method* presented in chapter 0 for the Mixteca case, it can be concluded that poverty alleviation in the region could be achieved and a sustainable future envisioned through the implementation of a solar energy system under the conditions analyzed in chapter 0, favoring scenarios 4, 6, 7 and 8 (Cluster 2). A highlight is that the reconfiguration of the societal landscape could be possible when adequate interrelationships between economic, technological, environmental, societal, political and cultural criteria are fulfilled and their targets are met. Nevertheless, the possibility that this aim will not be reached is also feasible.

The results of the *Scenario-based sustainability assessment* presented in chapter 0 explored the envisioned sustainable future of the diverse scenarios conforming to each path. The purpose is to identify the criteria that would allow or impede such sustainable futures within each scenario. The ideal path to a sustainable future is that in which each and every respective criterion within a scenario explores a direction towards the highest evaluation score, shown in Table 10, Table 11, Table 12 and Table 15 in color green. In this study, however, none of the scenarios showed a complete fulfillment of the sustainable trajectory. Nonetheless, as discussed in section 9.5, the path towards sustainability is defined through the targets, with each individual scenario directing its efforts towards it. This is the case for scenarios 4, 6, 7 and 8 (Cluster 2). This means that the current decisions being made for the proposed solar energy transition could be successful as a general pathway, however, some criteria will still fall short of meeting their targets, without affecting the overall good performance of the scenario cluster. Scenario 8 deserves attention, as it stands out from the Cluster in that all the descriptors / criteria (except for education) show the highest scores. So, the outlook for poverty alleviation through solar PV transition for scenario 8 is the most favorable and encouraging for a sustainable future among the four sustainable scenarios in Cluster 2.

In the absence of current sustainable decisions, scenarios 1, 2, 3 and 5 (Cluster 1) look to anticipate a dystopian future as the most likely unsustainable direction in the absence of actions today. As explained in section 8.3, the Mixteca situation will be similar to the XIX century, which means that the absence of action has perpetuated impoverishment. The lack of suitable measures to change this path has been persistent. Governmental policies along the decades seem not to be gaining a tangible result, so it is not surprising if the future seems to be an extension of the current situation and prolongs the worst-case scenario in Cluster 1.

In Cluster 1, *poor governmental* support and the *weak legal system* - as active leading descriptors in the CIB - fail to address an integrated energy system transition, hence the ICoS goals of *Securing human existence* and *Maintaining society's productive potential* seem to fall behind, while some improvements are seen on the third goal *Preserving society's options for development and action*. A suitable focus of priorities is not aligned in the future for Mixteca.

The sustainable aspect of the *Scenario-based sustainability assessment method* allowed us to distinguish between those criteria that are basic to a sustainable future (through the substantial rules), and those criteria which are the framework (the instrumental rules). This criteria identification provided by ICoS is not necessarily related to the main drivers identified in the scenario analysis because their roles in the system are different. The descriptors in CIB exert or receive influence from the rest of the descriptors, while the performance of the criteria in the ICoS framework indicates how far they are from sustainability.

The participation of each criterion in a sustainable future scenario is not related to a greater or lesser degree of sustainability, nor to its degree of importance. This analysis identifies the type of involvement in each sustainability goal. In this way, it could be valuable for decision-makers to present those criteria relevant to each specific goal, so that efforts towards a sustainable future can be considered and an action plan with appropriate steps can be designed. For example, given the efforts made over decades to tackle poverty, and seeing that securing human existence is a primary objective, a first step of action could envisage focusing on those criteria that comprise this first goal. All criteria are interrelated (see Figure 27), hence a dependent course of action will follow the impacts on the rest of the criteria.

A detailed criteria evaluation through the different sustainability rules allows a plenitude of essential detailed information about expectations, future benefits, drawbacks and possible tradeoffs. For example, the good performance of lowering emigration rates and increasing returning emigrants would provide a positive future where Mixteca could benefit from skilled people looking to improve the area. This positive outcome should be contrasted with lower remittances, an increase in population for which basic services need to be guaranteed, and potential local problems such as an increase in waste and air pollution. This information receives little attention when evaluated from a one-sided perspective where criteria values are compiled into one score. The integration of CIB-ICoS into one approach, the *Scenario-based sustainability assessment*, makes it possible to take an overview of the potential consequences of implementing a sustainable perspective by choosing one scenario or path over another. In this way, the stakeholders' judgments can be guided by the potential sustainable future scenarios and find the most suitable feasible way to implement them.

11.3 Outlook

This dissertation has highlighted the discussion of the societal aspects involved in the energy transition, and the following aspects have been identified and suggested for further research.

a) The solar energy transition discussed in this study is an opportunity to advance research on the recognition of societal impacts which influence this transition towards the challenges of structural inequality and poverty in low-income countries. If economic, environmental or technological scopes are prioritized above the social aspects, then the outcomes can result in higher inequality and regressive outcomes. The understanding of the social value of energy should drive the transition and not the other way around. Alleviating poverty in low-income countries is the proposed driver of energy transition, leading to consequences (seen as by-products) of a change of technology; use of renewable energy, reduction of environmental impacts, a reorganization of priorities where social needs are at the center, i.e., enhancing the wellbeing of the population. It is suggested to further explore the importance of social aspects, specifically poverty alleviation, as a trigger for the energy transition and to allow the debate to continue on this priority.

b) A way to re-arrange the socio-technical, political and economic relations conveys a deep transformation and connection to the traditional broader economic system view; contextual factors, as well as cultural, historical, political, economic, and socio-ecological factors influence inhabitants' support for and acceptance of energy transitions. In order to allow a suitable integration of societal needs, further approaches towards bottom-up actions according to the needs of the society should be considered and practiced; a suitable integration of vulnerable and marginalized communities combined with effective local governance is desired. In this study, Mixteca has already some traditional form of community service organization (*Tequio*, see section 3.8) that promotes societal cohesion since it is deeply rooted in its traditions. This could be used as a bottom-up approach and a stepping-stone to strengthen the involvement of the local community in solar energy projects, since the acceptance and participation of the population are necessary elements for the success of the system. This measure could also bring a reorganization of the socio-technical, political, environmental and economic interrelations within the society that would turn into sustainable development. Additional work toward this proposal is suggested.

c) In the path towards sustainable development, new system arrangements have emerged, as energy is no longer an isolated resource. Circular economy and Nexus initiatives (Albrecht et al., 2018) are recent proposals to optimize resources in a long-term process chain to diminish human impacts and cope with an environmental challenge. The energy transition could take place amid a system re-organization to include water-food-energy aspects in an integral design, keeping at the core the effective integration of societal aspects and the wellbeing of the population as a main objective.

d) This research focused essentially on small-scale solar energy production. However, further research could address large-scale developments (by external traditional ownership), or the escalation of the proposed system (by the inhabitants of the region), where in both cases Mixteca could expand its solar energy production into the neighboring states (across the Mixteca region), providing greater energy security to the rural area, improving wellbeing and making the state of Puebla a solar hub. The second alternative might be the bottom-up alternative which would bring the most noticeable wealth distribution in the area; empowering the inhabitants to create their own living, thus, poverty alleviation. Further research would establish the extent of such an alternative and its applicability to the area.

e) This study focused on the aim of poverty alleviation that a solar energy transition could bring, however the provision of energy does not necessarily enhance the wellbeing of the population. Further research on the possible negative social impacts the provision of energy would bring to the population is needed. For instance, access to electricity does not mean an immediate improvement in wellbeing, as the cost of the service increases families' expenses, and if salaries are not adequate, the poverty gap increases. Examples where the cost of electricity and services associated to it plays a major role in determining whether poorer households can benefit from electricity access can be found in Trace et al., (2022). The need to acquire household appliances in order to benefit would also increase the expenses. A change in electricity provision might also affect families' budgets. If the cost increases, people could reject the change despite environmental benefits; social costs associated with education and information dissemination should be accounted for. Some additional risks associated should be considered, for instance, children with internet access could become vulnerable to predatory networks of abuse, pornography, drug cartel recruitment, cyber offenses, kidnapping. Hence further research on the possible negative social impacts is suggested.

f) Rural communities like Mixteca (both in Mexico, and in other Latin American countries) face a major challenge in governance. Given that governance is a main driver which could promote or impede the energy transition, and hence poverty alleviation, further research could be focused on how to reach a level of “organization / leadership / rule” which works despite the governance uncertainties and creates possibilities and opportunities to make an energy transition happen.

g) Chapter 0 discussed the different aspects of transferability identified through this study. The ultimate level, “practical knowledge”, is related to the implementation of the case, taking this research into practice. In order to take this study into action, further research is needed as to how to make it happen; designing frameworks, policies, guidelines, and identifying possible actors and stakeholders. Further interdisciplinary work is needed.

h) One possible application of the *Scenario-based sustainability assessment approach* could be to support political, social, environmental and technological decisions on complex issues with long-term implications. Supporting cooperatives for distributive solar energy generation is not necessarily attractive from the current political perspective; investment in education is also a decision whose results are not immediate, nevertheless these decisions are necessary to fulfill a sustainable future development as envisioned by the scenarios and provided through the application of the approach. One area of suggested further research would address how to make long-term decisions happen in low-income countries when prompt results are needed.

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Appendix A

Table 16. Municipalities that conform Mixteca in the state Puebla with population breakdown. Source (INEGI, 2021)

Municipality	Total inhabitants	Men	Women
Acatlán	37 471	17 313	20 158
Ahuehuetitla	1 900	884	1 016
Albino Zertuche	1 897	873	1 024
Atexcal	3 978	1 915	2 063
Axutla	974	449	525
Chiautla	21 000	10 167	10 833
Chigmecatitlán	1 250	573	677
Chila	4 839	2 268	2 571
Chila de la Sal	1 484	717	767
Chinantla	2 402	1 128	1 274
Coatzingo	3 113	1 480	1 633
Cohetzala	1 408	709	699
Coyotepec	2 431	1 122	1 309
Cuayuca de Andrade	3 284	1 583	1 701
Guadalupe	6 122	2 839	3 283
Huatlatlauca	6 809	3 101	3 708
Huehuetlán el Chico	8 957	4 353	4 604
Huehuetlán el Grande	7 581	3 673	3 908
Huitziltepec	5 761	2 770	2 991
Ixcamilpa de Guerrero	3 790	1 795	1 995
Ixcaquixtla	9 305	4 444	4 861
Jolalpan	13 723	6 571	7 152
Juan N. Méndez	5 544	2 738	2 806
La Magdalena Tlatlauquitepec	589	297	292
Molcaxac	6 559	3 077	3 482
Petlalcingo	10 166	4 740	5 426
Piaxtla	4 606	2 217	2 389
San Jerónimo Xayacatlán	3 681	1 713	1 968
San Juan Atzompa	932	477	455
San Miguel Ixitlán	534	251	283
San Pablo Anicano	3 756	1 790	1 966
San Pedro Yeloixtlahuaca	3 508	1 684	1 824
Santa Catarina Tlaltempan	850	427	423
Santa Inés Ahuatempan	6 649	3 180	3 469
Tecomatlán	6 033	2 960	3 073
Tehuitzingo	11 792	5 584	6 208
Teotlalco	3 321	1 620	1 701
Tepexi de Rodríguez	22 215	11 143	11 072
Totoltepec de Guerrero	1 271	577	694
Tulcingo	9 963	4 649	5 314
Tzicatlacoyan	7 345	3 633	3 712
Xayacatlán de Bravo	1 654	753	901
Xicotlán	1 276	606	670
Xochitlán Todos Santos	6 745	3 196	3 549
Zacapala	4 628	2 181	2 447

Appendix B

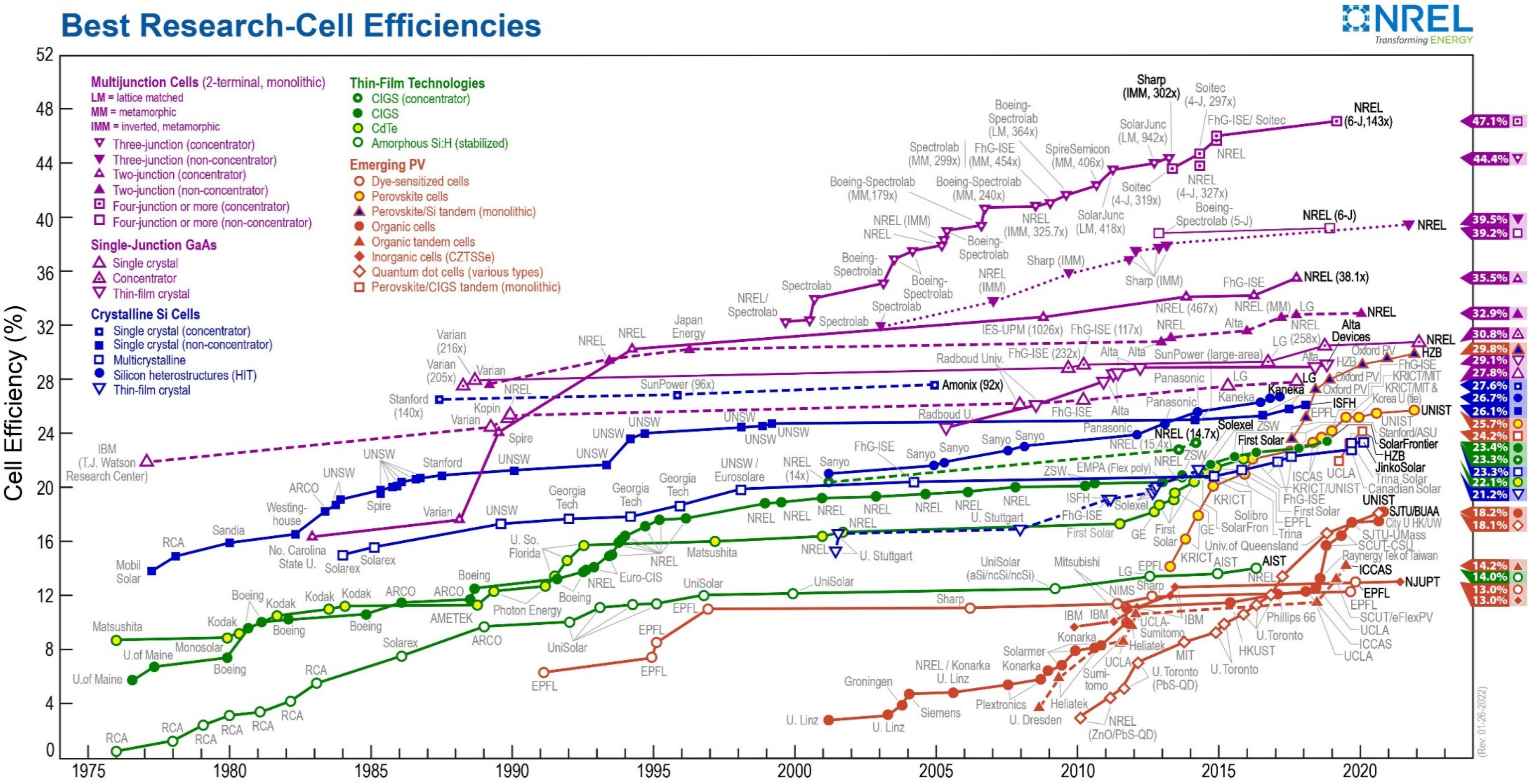

Figure 35. Comparison chart PV solar cells efficiency. Rev.12-14-21 by (NREL, 2022a)