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DEVELOPING A SDGs-BASED FRAMEWORK FOR ASSESSING THE SOCIO-ECONOMIC IMPACT OF ELECTRIC AIRCRAFT

A lithium mineral extraction perspective

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Abstract

The expected exponential growth of lithium batteries in aircraft technology and the growth of the use of lithium on the automotive industry and other industries have been arising many concerns. Battery powered electric aircraft have been the target of many research studies in the recent years and many believe they could be the key to aviation's zero emissions goal. This study investigates the implications of the electrification of the air transport industry and analyzes its socioeconomic impact, focusing particularly on lithium mining and exploring its influence on four of UN's Sustainable Development Goals.

Building up on a modern methodological approach of socio-economic impact assessment, the key of the alignment of the SEIA framework and UN's SDGs is basing on the chosen SDG indicators to perform the baseline review and consequently assessing the impact basing on the results of the baseline review stage. The versatility of the methodology adaptation is the key takeaway of this research. On a social level, the rise of electric aircraft and increase of demand and production of lithium batteries will negatively impact the quality of the water used in the mining areas, increasing migration and CO_2 emissions. Nevertheless, it could improve adherence to sustainable sources of energy raise awareness towards good practices in mining. On an economical perspective, it can grow Chile's GDP and generate employment. Further investment in the industry and its yearly production capacity could be crucial for a steady and sustainable economic development and improvement of the communities' quality of life.

Keywords

Resumo

O esperado crescimento exponencial das baterias de lítio na tecnologia das aeronaves e o crescimento do uso do lítio na indústria automotiva e outras indústrias têm gerado muitas preocupações. Aa aeronaves elétricas movidas por baterias têm sido alvo de muitos estudos de pesquisa nos últimos anos e muitos acreditam que podem ser a chave para a meta de zero emissões da aviação. O presente estudo investiga as implicações da eletrificação da indústria do transporte aéreo e analisa o seu impacto socioeconómico, focando particularmente na exploração de minas de lítio e explorando a sua influência em quatro dos Objetivos de Desenvolvimento Sustentável da ONU.

Baseando numa abordagem metodológica moderna de avaliação de impacto socioeconómico, a chave do alinhamento da estrutura AISE e dos ODS da ONU é basear-se nos indicadores ODS escolhidos para realizar a revisão do baseline e, consequentemente, avaliar o impacto com base nos resultados da fase da revisão do baseline. A versatilidade da adaptação da metodologia é o ponto chave desta pesquisa. A nível social, a ascensão das aeronaves elétricas e o aumento da demanda e produção de baterias de lítio impactarão negativamente a qualidade da água utilizada nas áreas de exploração do lítio, aumentando a migração e as emissões de CO_2. No entanto, poderá melhorar a adesão a fontes sustentáveis de energia e conscientizar sobre boas práticas na exploração do lítio. Do ponto de vista económico, poderá aumentar o PIB do Chile e gerar empregos. Mais investimentos na indústria e na sua capacidade de produção anual poderão ser cruciais para um desenvolvimento económico estável e sustentável e para melhoria da qualidade de vida das comunidades.

Palavras-chave

Lítio, aeronave elétrica, extração de minerais, análise socioeconómica de impacto, objetivos de desenvolvimento sustentável.

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Acronyms and abbreviations

ACARE - Advisory Council for Aeronautics Research in Europe

ACI – Airport Council International

ADAP – Aviation Data and Analysis Panel

ASA – Aviation Satellite Account

ATAG - Air Transport Action Group

CH4 - Methane

CO_2 - Carbon Dioxide

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

COVID-19 - Coronavirus Disease 2019

DC – Direct Current

EAG – Expert Advisory Group

EIA – Environmental Impact Assessment

EU28 – European Union 28

EV – Electric Vehicle

FAA - Federal Aviation Administration

GATP - Global Air Transport Plan

GDP – Gross Domestic Product

GHG - Greenhouse Gas

GTTM - Global Tourism and Transport Model

HEA – Hybrid Electric Aircraft

IATA - International Air Transport Association

ICAO - International Civil Aviation Organization

ISEC – Instituto Superior de Educação e Ciências

ISIC - International Standard Industrial Classification of All Economic Activities

ISO - International Organization for Standardization

LCO – Lithium Cobalt Oxide

LFP – Lithium Iron Phosphate

LH2 – Liquid Hydrogen

LiB – Lithium Battery

LMO – Lithium Manganese Oxide

NCA – Lithium Nickel Cobalt Aluminum

NGAP - Next Generation of Aviation Professionals Program

NMC – Lithium Nickel Manganese Cobalt

NOx – Nitrogen Oxides

RPK – Revenue Passenger Kilometers

SAF – Sustainable Aviation Fuel

SDG – Sustainable Development Goal

SEIA – Socio-Economic Impact Assessment

SRIA - Strategic Research and Innovation Agenda

SSP - Shared Socio-economic Pathways

SWOT - Strengths, Weaknesses, Opportunities and Threats

UN – United Nations

1. Introduction

The present study was designed and conducted to be submitted and showcased as public proof for the obtention of the degree of Master of Air Transport Operations by ISEC Lisboa. The study seeks to develop a framework that harmoniously unites the conventional socio-economic impact assessment methodology and UN's sustainable development goals' targets and indicators to assess the socio-economic impact of future aviation, namely the electric aircraft, from a sustainable perspective in social and economic terms.

1.1. Study background

The 2020 edition of the European Aviation Environmental Report based on 2019 data shows that in 2016, aviation emissions accounted for 3.60% of the total European Union's GHG emissions and 13.40% of transport emissions in general. European aviation alone accounted for 20% of the global CO_2 emissions in 2015. Due to the severity of the scenario, continuous development of environmentally sustainable technologies across industries has been rising aiming to counteract the negative impact. In the last decade, for instance, the aerospace sector has spent around 15 billion dollars each year on research for aircraft technology efficiency (ATAG, 2020).

As a result, there has been a significant increase in the research and implementation of environmentally sustainable technologies (Räikkönen et al., 2016; Goldberg et. al., 2018). Regulations and international laws designed and regulated by authorities such as the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), the Federal Aviation Administration (FAA), the International Organization for Standardization (ISO), among many others, aiming to decrease and control the negative effects of air transport on the environment are constantly being proposed, adjusted and implemented according to the evolution of the circumstances and necessities. Ranging from the adoption of sustainable fuel to the design and development of hybrid and electric aircraft, the draft of a "green" future for aviation has been gradually coming to life and impacting the industry.

In 2011, The European Vision Flightpath 2050 initiative was launched and its report was published during the Aero Days 2011 in Madrid by the High-Level Group for Aviation Research (European Commission, 2011). The goals to maintain European leadership and serve societies' needs can only be reached when all aviation research stakeholders work together along the guidelines provided by the Strategic Research and Innovation Agenda (SRIA) prepared by the Advisory Council for Aviation Research and Innovation in Europe (ACARE). On an environmental and energetic level, Flightpath 2050's goals include the plan of technologies in 2050 allowing a 75% reduction in CO_2/pax/km and a 90% reduction in NOx emissions, and noise shall be reduced by 65%, compared to the capabilities of a typical brand-new aircraft back in the year 2000 (European Commission, 2011). Aircraft movements should also be completely emission-free when taxiing by 2050, and air vehicles be designed and manufactured to be recyclable. The European continent is also set to be established as a center of excellence on sustainable alternative fuels, including those for aviation. Following a rigorous energy policy, by 2050 Europe shall be at the forefront of atmospheric research and the lead in the formulation of a prioritized environmental action plan and establishment of global environmental standards (European Commission, 2011). In line with Flight Path 2050's goals, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) constitutes the world's first targets for CO_2 emissions reductions (European Commission, 2011). The industry was set to improve 1.50% a year in average fleet fuel efficiency from 2009 to 2020, stabilize net CO_2 starting 2020 through carbon-neutral growth and reduce aviation related CO_2 emissions to half of 2005 levels by the year 2050 (European Commission, 2011).

Battery powered electric aircraft have been the target of many research studies in the recent years and have been pointed out to be the key to the achievement of aviation's zero emissions goal (Deloitte, 2021). Deloitte (2021) highlights that all of the propulsion systems should be replaced by fully electric propulsion systems and combustion engines replaced by lithium batteries, and consequently, the challenge is doubled by the necessity of producing clean energy to recharge the batteries with zero emissions, as well as mitigating the impact of lithium mineral mining on society, economy and environment. Prior to the commercialization of lithium batteries which took place in the early 2000s, the lightest metal and solid element was mostly used in

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ceramics, glass and aluminum industry. The use of lithium later evolved to medication and technologies, namely electronic devices and electric vehicles. Aviation's zero emissions agenda implies a massive increase in the use of lithium batteries and consequently, a significant need of massive extraction of raw lithium material for production in a larger scale as the pace of evolution of electric cars and other means of transport is equally booming and expected to grow (Zeng et al., 2019; Xu et al., 2020).

1.2. Problem statement

The expected exponential growth of lithium batteries in aircraft technology along with the growth of the use of lithium on the automotive industry and other industries arises many concerns regarding its demand, supply, production and recycling. The electrification of the air transport industry is set to intensify in the next 10-15 years. In order to fulfill Flightpath 2050's agenda (European Commission, 2011), the industry is required to manufacture, certify and operate a considerably high number of hybrid-electric and all-electric aircraft.

The manufacturing of the aircraft will have a big impact on the world's lithium supply and demand specially given that the production and consumption of electronic devices and electric vehicles is also expected to increase even more than it has in the past decades. The impact dimension will not only be environmental, but also social and economical. One of the key concerns is whether the world reserves of lithium will be enough to meet lithium demand in the coming years. Another key concern is how the emissions and pollution generated by lithium mining compare to traditional aircraft emissions and whether or not It could affect the real impact of electric aircraft attributing certain levels of emission indirectly on a broader perspective considering the high amount of water used during the mining process and the electricity used during mining process and later for recharging purposes, among other factors.

The air transport industry's electrification phenomenon will have an impact on the society and the economy, given that it will influence the quality of life, economic prosperity, resources availability and sustainable development, among other aspects. The pollution generated by the extraction and refinement of massive quantities of lithium might be too significant and indirectly affect the sustainability of hybrid-electric

and all-electric aircraft despite the emission reduction. Furthermore, it is important to understand the socio-economic impact that the aggravated lithium mining triggered by the air transport electrification agenda will have on direct and indirect stakeholders.

1.3. Study aims and objectives

The purpose of this study is to investigate the implications of the electrification of the air transport industry and analyze its socioeconomic impact, focusing particularly on lithium mining and exploring its influence on UN's Sustainable Development Goals. The socio-economic impacts are analyzed basing on UN's SDGs, namely the top four goals on which the mining industry is considered to play a very direct role on, according to Lewis (2016).

The study seeks to explore the relationships and interactions between the electrification of the air transport industry, the lithium mineral extraction and UN's SDGs, and develop a socio-economic impact assessment framework that takes into consideration four of the SDGs which according to Lewis (2016) experience a more direct impact from the mineral extraction industry. In this specific case, the lithium mineral extraction industry represents the focus. In order to achieve the defined aims for this study and provide answers to the formulated research questions, a literature review is carried out to provide an overview of the current state of art and emerging trends and themes surrounding these subjects.

1.4. Research approach

In order to investigate this research problem, four research questions have been formulated which will guide this study and shape a better understanding of the relationships and interactions between the air transport industry, electric aircraft, lithium mineral extraction and the selected SDGs which this research will focus on. In this section, the research approach is explained and justified in order to address the following research questions:

1. What is the relationship between the electrification of the air transport industry, the lithium mineral extraction industry and the UN's SDGs?

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2. To what extent could the exponential increase on demand of lithium batteries accentuated by the electrification of the air transport industry affect lithium mineral extraction industry alignment and/or compliance with the SDGs?

3. What are the advantages and disadvantages of the electrification of the air transport industry to the relationship between the lithium mineral extraction industry and the SDGs?

4. What is the role of the electrification of the air transport industry in the compliance/achievement of the SDGs by the lithium mineral extraction industry?

The main purpose of this research is to explore and demonstrate the relationships and interactions between the electrification of the air transport industry, the lithium mineral extraction and UN's SDGs, while developing a socio-economic impact assessment framework which takes into consideration four of the SDGs which according to Lewis (2016) have the most direct impact on the mineral extraction industry.

1.5. Study assumptions

The investigation of the correlations performed in this research is relatively new-fangled as it is observed in the literature review. The chosen country for analysis was Chile, due to the availability of related data compared to the remaining top lithium mining countries. Nevertheless, available data is quite limited. Several difficulties were faced due to the limited access to relevant data, bringing into attention the need to urge governments, organizations and companies to make them available to the public, namely for research development purposes but also for consultation and knowledge.

1.6. Structure

Following this introductory section which briefly describes the study background and problem under investigation, as well as the aims and objectives, research approach, and approach assumptions. This study is composed of four more chapters. In the literature review chapter, the state of the art is presented and discussed, pointing out different recent studies on several topics related to the methodology under development such as aviation and GHG emissions, sustainable development goals,

lithium mineral extraction, electric aircraft and the socio-economic impact assessment and its applications in general but focusing on its application in aviation.

The methodology chapter includes the methodological approach, guidelines to be followed, the justification of each of the methodological choices and the outcome expected from each of them. In the 4th chapter, the baseline review is performed, presenting and analyzing the data related to the SDGs under investigation, and the results are discussed while relating to the literature review performed throughout the second chapter. In the final chapter, the conclusions drawn from the framework's development and outcomes are presented, and also the study limitations are restated and some recommendations and further research suggestions are pointed out.

2. Literature review

To better understand the state of the art of the proposed research topic, a literature review is conducted. In this section, the author identifies key themes related to the topic, in order to gain understanding of the existing research and relevant debates. Aside from identifying the key themes, this chapter's purpose is to highlight knowledge gaps in need to be addressed and aspects that have not been addressed or researched in adequate detail.

Figure 1 illustrates the key themes identified in existing research, as well as the correspondent sources. This chapter provides a clear and concise vision of the trends, patterns, conflicts, contradictions and gaps of the existent literature regarding the electrification of the air transport industry, its socio-economic impact and the sustainable development goals.
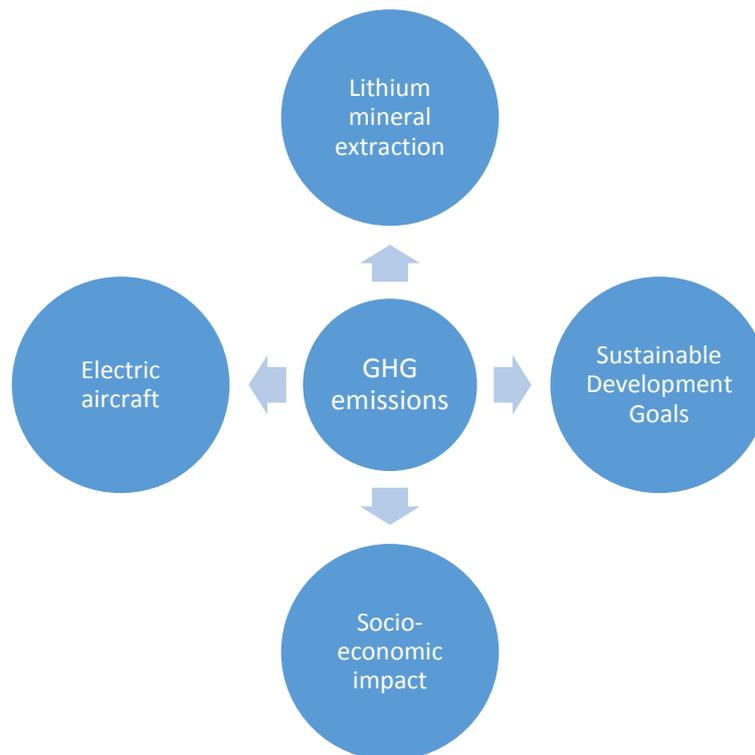
Figure 1: Diagram of literature review's key themes

2.1. Aviation and GHG emissions

Climate change is one of the biggest challenges faced by this generation. Its gradual aggravation has resulted in numerous environmental issues and enabled awareness of its short and long-term consequences on the environment and its impact on our lives and the future of the planet. Air transport is among the fastest-growing industries in the world. Due to the Covid-19 pandemic and the subsequent travel bans among other restrictions, the industry has been severely affected, with its global impact in economy having decreased in more than 50% (ATAG, 2020). On a positive note, the pandemic has also had a significant impact on the carbon footprint of the air transport industry, which, among other industries, plays a key role in the climate change mission as it can be acknowledged in this literature review.

The air transport industry has the greatest effect on the environment due to the fact that aircraft emit their exhaust gas pollutants directly to the upper troposphere and lower stratosphere. The aircraft is the most pollutant mean of transport in the world in terms of CO_2/pax/km (EASA, EEA, & EUROCONTROL, 2020). According to EASA, EEA & EUROCONTRO (2020), aircraft emissions account for about 2-3% of the total GHG in the atmosphere and could reach a 27% mark by 2050. Aircraft emissions interact in the upper troposphere and lower stratosphere and are responsible for changes in ozone and methane concentration thus forming contrails. The most important aviation-derived factors influencing the atmosphere are carbon dioxide (CO_2), nitrogen oxides (NO_x), methane (CH_4), water vapor, contrails, cirrus clouds, sulphates and soot aerosols.

In 2016, Peters used a Global Tourism and Transport Model (GTTM) to explore policies to reduce tourism and travel-related air transport CO_2. The research explored air transport development in a large range of socio-economic background scenarios (ICAO, Green Sky and Green travel). Nevertheless, the results revealed significant economic and emissions' growth (from 130%-2310%, between the year 2015 and 2100). The author also explored dedicated measures for emissions reductions, but neither technology nor biofuels would be capable of reducing emissions compared to 2020. High taxes policy also revealed ineffective to stopping CO_2 emissions' growth. Therefore, the author observed that only a global airport slot capacity limit proved effective in regards to emission reductions compared to 2015 emissions, and 80-90% emission reductions is

only feasible with a steady development of the air transport industry. Peters' findings were furthermore validated by Janic (2017), which conducted an assessment of the potential of conventional oil-kerosene (JET-A1/8) and alternative synthetic and biomass-derived synthetic paraffinic kerosene (SPK) and liquid hydrogen (LH$_2$) fuels for "greening" the commercial air transport industry through fuel consumption reduction and related GHG emissions. The methodology adopted by Janic showed that the full introduction of alternative SPK fuels could only result in a peripheral reduction of the cumulative direct emissions of CO$_2$. Similarly, alternative LH$_2$ fuels would bring substantive reduction of the cumulative CO$_2$ emissions, and could have contributed to the achievement of global emission targets if they had been introduced earlier.

Another similar finding is defended by Cox et al. (2018). Cox's study of the life cycle assessment of air transportation and the Swiss commercial air transport fleet showed that despite the significant improvements in per passenger kilometer emissions resulted from future aircraft improvement scenarios, the environmental challenges related to air transportation are expected to continue increasing due to increase on demand. The main cause of many environmental impacts caused by air transportation can be explained by the upstream impacts of kerosene production and not through direct aircraft operations. Air transportation was severely affected by the Covid-19 pandemic (ATAG, 2020). As per ATAG (2020), jobs supported by the industry reduced by 52.50%, the economic activity supported by air transportation also decreased by 51.50%, resetting the baseline for growth of aviation up until 2050. ATAG's report defends that aviation can meet its climate goal by 2050 if an acceleration in aircraft and engine technology development including faster progress towards electric, hybrid and hydrogen powered aircraft takes place, among other significant efforts.

Following the pandemic, the daily global CO$_2$ emissions decreased by −17% by early April 2020 compared with the mean 2019 levels, just under half from changes in surface transport and at their peak, emissions in individual countries decreased by −26% on average (Le Quéré et al., 2020). While many may defend that this decrease signified a carbon reset towards the 2050 carbon-neutral target, Le Quéré et al. (2020) highlighted that during previous economic crises, decreases in emissions did not last much long, following postcrisis rebounds which restored emissions to their original trajectory, except when the crisis were caused by energy factors.

"The economic crisis associated with COVID-19 is markedly different from previous economic crises in that it is more deeply anchored in constrained individual behavior. At present it is unclear how long and deep the crisis will be, and how the recovery path will look, and therefore how CO_2 emissions will be affected. Keeping track of evolving CO_2 emissions can help inform government responses to the COVID-19 pandemic to avoid locking future emissions trajectories in carbon-intensive pathways (Le Quéré et al., 2020)"

Gossling et al. (2021), modelled a COVID-19 recovery based on a feed-in quota for non-biogenic synthetic fuels that would decarbonize fuels by 2050, as well as a carbon price to account for negative externalities and as an incentive to increase fuel efficiency. His results suggested that up until 2050, air transport demand will continue to grow, although slower than in ICAO's recovery scenarios, exceeding 2018 demand by 3.7–10.3 trillion RPK, and that synthetic fuels, produced by 14–20 EJ of photovoltaic energy, would make it possible to completely phase out fossil fuels and to avoid emissions of up to 26.5 Gt CO_2 over the period 2022–2050.

Amidst rising concerns regarding aviation-related emissions, public pressure has increased, especially in Europe, giving emphasis to the "flight shaming" movement as well as discussions within different European. Under increased scrutiny, and following pledges made by other emission-intensive sectors, the European aviation sector adopted several resolutions to significantly reduce its emissions and a proposed approach to reach carbon-neutrality by 2050. To achieve these targets, the aviation industry is currently shifting from focusing solely on technological and operational improvements towards developing new systems and alternatives to kerosene to significantly reduce the emissions of the sector (Deloitte, 2021).

The Aviation Technology Roadmap by 2040 (for short-haul flights) aims to achieve Zero-emissions Aviation by the year 2040 through the gradual achievement of hybrid-electric aviation (2030-2035), zero-carbon aviation (2035-2040) and zero-emissions aviation (2040) (Deloitte, 2021). Hybrid-electric aviation is set to be achieved through the implementation of hybrid-electric powertrains to partially reduce GHG emissions by integrating electric motors powered by batteries or fuel cells to complement

combustion engines or by using combustion engines to drive electric generators powering electric motors (Deloitte, 2021).

Between 2035 and 2040, kerosene is set to be replaced by non-carbon fuels (namely hydrogen), which can be combusted in modified turbines or reacted in fuel cells to power electric powertrains – nevertheless, this can only become a zero-carbon cycle, the hydrogen must also be produced at zero carbon emissions (Deloitte, 2021). As of 2040, all propulsion systems shall be replaced by fully electric propulsion systems, and combustion engines replaced by electric motors powered by batteries to drive propellers or ducted fans – the electricity must also be produced without emissions. Hydrogen-powered combustion aircraft are expected to reduce climate impact by 50-75%, while hydrogen fuel cell electric aircraft and battery-powered electric aircraft are expected to reduce climate impact by 75-90% and 100% respectively (Deloitte, 2021).

Shifting to battery-powered electric aircraft will also promote maintenance costs reduction which usually accounts for about 20% of the total cost of aircraft. It will also promote reduced noise pollution through slower propeller rotation speed and fewer moving parts, shorter take-off distance due to improved acceleration resulting from increase static thrust, and lower operating costs due to energy costs reduction and the simplicity and longevity of electricity-powered motors and drivetrains (Deloitte, 2021).

Hasan et al. (2021) presented an integrated mitigation approach based successful discrete measures, combined with other methods that can promote the mitigation of GHGs from the aviation sector: alternate fuels and fuel switching, fuel cells, solar power, efficiency measures, market-based policies, improved intermodal transportation planning, fleet modernization and operational approach.

2.2. Sustainable development goals

According to the United Nations, sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The pillars of sustainable development are economic growth, social inclusion and environmental protection. The Sustainable Development Goals (SDGs) were established in 2015 by the United Nations (UN) under

the mission statement: "a blueprint to achieve a better and more sustainable future for all people and the world by 2030".

The 17 goals are a universal call to eradicate poverty and improve the lives of everyone, everywhere. Each goal has 8-12 targets, totaling 169 targets. Each target has 1-4 indicators, approximately 300 indicators in total, to track the progress in achieving the targets. The UN defends those investments in sustainable development will aid tackling climate change by reducing greenhouse gas emissions and building climate resilience, and consequently, action on climate change will drive sustainable development. Mitigating climate change and fostering sustainable development are two mutually reinforcing sides of the same coin, and sustainable development cannot be achieved without climate action. Many SDGs address the core drivers of climate change.

Figure 2: Sustainable development goals – Source: United Nations, 2022

Cavallet and Cherubini (2018) proposed a quantitative and traceable approach to adapt existing indicators from updated environmental impact assessment methods to the SDGs, introducing an approach for SDG analysis based on life-cycle impact assessment methods and showed that climate change benefits of renewable jet fuels produced from forest residues available in Norway are larger in the medium/long-term and short-term. The authors emphasized that future refining and development of indicators more specifically tailored for the SDGs, ideally established through

international multidisciplinary efforts, will be instrumental to identify, manage and prevent potential conflicting implications of biofuel systems for the SDG agenda.

Spies (2019) defended that technology and technological innovation are seen as a key contributing factor towards sustainable development and the SDGs, and sustainable development could be influenced by technological innovation, and it is evident in literature that society and technology co-evolve and influence one another. By aligning the objectives of industries with those of the technologies by means of SDGs, industries can positively influence the SDGs, and therefore also sustainable development, with the help of technology. Advancing from his point of view, electric aircraft can be categorized as a key contributing factor towards sustainable development. Aligned with the SDGs, lithium mineral mining can influence the achievement of the SDGs.

Omer and Noguchi (2020) investigated the interactions between building materials and the SDGs, attempting to establish a knowledge-based decision support system for policy-makers, designers and construction stakeholders regarding the implementation of 2030 agenda. The developed framework showed that investigating the contribution of building materials in the achievement of SDGs and target impose the demonstration of basic understanding and awareness between different stakeholders on how the classification and the selection of building materials have a significant impact in reaching sustainability and mitigating climate hazards. The framework is expected to convert the SDGs and their targets into a measurable tool to be achieved in the practice and guide the decision-making process successfully.

Liu et al. (2020) employed a Representative Concentration Pathways–Shared Socio-economic Pathways (RCP-SSP) framework and the Asia-Pacific Integrated Model/computable general equilibrium (AIM/CGE) integrated assessment model to identify the global multi-sectoral consequences of socioeconomic conditions through 2050 under future SSP scenarios. Their study showed that in many respects, socioeconomic conditions are more important than climate policies in achieving SDGs, particularly SDGs concerned with food security and energy affordability, as well as in simultaneously achieving multiple SDGs, and concluded that the advantages of a joint effort to implement climate policies and promulgate socioeconomic changes should be recognized by policy makers.

Similarly, Ibeh and Walmsley (2021) showcased substantial enhancements on achieving the SDGs can be advanced by good Environmental Impact Assessments (EIAs) and strict adherence to regulations, requiring a close collaboration and cooperation between environmental practitioners and the decisionmakers to ensure that the consideration of the SDGs is an integral part of every EIA, maximizing opportunities for sustainability. The study identified the key challenges of achieving the SDGs in Africa as: data issues, conflict, governance issues and weak institutions, finance, climate change, and demographics and migration. The authors aligned the SDGs to the EIA process. The methodology requires that environmental and social practitioners define objectives, establish processes, set timelines, as well as make and implement decisions to meet set targets for proactive development of achievable sustainable outcomes, including ensuring that programs, plans and policies are aligned with the transformational change agenda of the SDGs, thus planned outcomes of EIA are aligned with actions to achieve targets for social and economic goals and environmental improvement and restoration.

In 2022, ICAO published an article on their "Uniting Aviation" dedicated webpage reporting the contributions of air transport to the UN's SDGs. As per the goal 1 (no poverty), ICAO contributes by developing a strategic planning document for a possible Global Air Transport Plan (GATP) (ICAO, 2022). The intent is to provide a long-term vision and goals for harmonizing the air transport framework in all Member States and to define a strategy for fostering the development of a robust and economically viable civil aviation system worldwide through targeted economic policies and support activities (ICAO, 2022).

It contributes to the second goal through the modernization of the global air traffic management system improves flight operations' reliability, enhancing accessibility to remote areas and facilitating urgent access to sufficient food for everyone year-round. Aviation supports people's well-being and health by carrying medicine and vaccines across long distances under-regulated storage conditions (ICAO, 2022). Air transport also gives necessary medical care through air ambulances to remote communities, helping achieve the third goal. ICAO supports the fourth SDG through its Next Generation of Aviation Professionals Program (NGAP) and also convenes training seminars for the Member States, increasing the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and

entrepreneurship, in the world of aviation and thus contribute directly to achieving SDG 4 (ICAO, 2022). ICAO's Gender Equality Program contributes to this SDG by promoting women's participation and enhancing their presence at all professional posts and higher employment levels in the global aviation industry (ICAO, 2022).

While ICAO does not directly contribute to SDG 6, the aviation industry fights to reduce its environmental footprint, including through the sustainable management of water. For example, traditional cleaning methods for a wide-body aircraft could use up to 13 thousand liters of water (ICAO, 2022). But new 'dry wash' techniques for aircraft minimize water use by 95% compared to traditional cleaning methods. Also, through the convening of international Conferences and Seminars, ICAO encourages exchanging information and best practices amongst stakeholders on clean energy to reduce the impact of airport operations on the environment and promote cooperation action globally (ICAO, 2022). These actions contribute to the seventh SDG by enhancing international cooperation to facilitate clean energy research and technology access. ICAO contributes to SGD 8 by promoting higher economic productivity and employment for all. As well as providing employment, aviation contributes USD 2.7 trillion to global economic activity, 3.6% of the worldwide total (ICAO, 2022). ICAO also supports inclusive green growth and fosters green economy initiatives to enable new green technologies and clean energy for the aviation sector, investments in aviation biofuels produced through sustainable agricultural practices and processing processes, creating green jobs They will support many activities such as developing goods delivery business models, particularly online sale of products and food, an inspection of infrastructure and land, monitoring of people, agriculture and the environment, and medical logistics and humanitarian activities.

ICAO is responding to innovations from the industry and focusing attention on the need to address the safe, secure and efficient insertion of new types of aircraft such as drones and flying taxis, accompanied by the introduction of new types of operators and operations. Goal 10 - Air transport provides connectivity which can reduce inequality between individuals and countries by creating trade links and providing access to goods and services for those in remote communities. While not everyone can afford air transport services, the democratization of air travel has made these services available to more people today. Since 1970, the real cost of air travel has been reduced by 70%.

Goal 11 - Aviation-related infrastructure is a significant part of urban and rural communities worldwide and contributes to the connectivity of populations through integrated transport links. ICAO promotes air connectivity as a vital driver in developing strategic and integrated transport infrastructures, enhancing people and businesses' mobility through all transportation methods. ICAO contributes to SDG 12 by developing tools to monitor the sustainable development impacts of sustainable tourism in creating local jobs. Airlines and airports worldwide have recognized the importance of reducing, reusing, and recycling waste (ICAO, 2022).

ICAO also contributes to SDG 13 by coordinating emergencies through its crisis response policy and disaster risk reduction strategy in aviation. These initiatives help increase Member States adaptive capacity when faced with natural disasters and strengthen the resilience of aviation infrastructure to natural disasters. ICAO does not directly contribute to SDG 14. Still, the aviation industry contributes by having airports and airlines worldwide working to conserve the oceans, seas, and marine resources, including conservation programs and raising awareness among passengers. Goal 15 - In collaboration with government and conservation organization partners, the aviation industry combats the illegal wildlife trade that takes advantage of air transport's connectivity. ICAO and its Member States have been working with the aviation industry to foster sustainable Aviation Fuels (SAFs) development and deployment. This action will contribute to the sustainable use of terrestrial ecosystems, such as forests.

Goal 16 - ICAO contributes to this SDG by eradicating the trafficking of people and promoting the rule of law at the national and international level. Small unmanned aircraft are essential to monitor at-risk societies, collect data for humanitarian response and support delivery of life-saving air. ICAO also works to reduce violence and related death rates worldwide by developing global standards and policies about global flight tracking and conflict zone risks and the use of small unmanned aircraft. Implementing the GASP and the international support for the prioritization of aviation in development frameworks contributes to SDG 17 by enhancing policy coordination and coherence while ultimately respecting each country's policy space. The Organization also assists States in developing strategies for cooperation with Civil Aviation Authorities and non-State entities involved in civil aviation.

2.3. Lithium mineral extraction

The global energy has been gradually shifting from fossil fuels to renewables. Electricity is expected to become the main source of energy used worldwide, namely in transportation, increasing exponentially the use of lithium batteries. Salar de Uyuni in Bolivia is the largest source of lithium in the world. Lithium was discovered by Johan Arfvedson in 1817 from the mineral petalite. It is the lightest of all metals and solid elements and its extraction brings a particularly significant trade off with the environment. It can be recovered from hard rock sources like spodumene, and from brine sources.

Alternative and innovative extraction processes involve lithium from lepidolite, from petalite and zinnwaldite, from clays and from electrolysis (Honaker et al., 2018). Types of lithium deposits include closed-basin brines, pegmatites, hectorites, oilfield brines, geothermal brines and jadarites. Lithium is sold and used in two main forms, lithium carbonate and lithium hydroxide. According to Azevedo et al. (2018), the five (5) main lithium battery technology options: lithium cobalt oxide (LCO), lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum (NCA), lithium iron phosphate (LFP) and lithium manganese oxide (LMO). Ziemann et al. (2018) assessed the trend in lithium demand and the possible effects of automotive battery recycling and concluded that battery recycling could result in a significant oversupply of secondary material if its quality is not high enough to allow for reprocessing in battery production. The study also highlighted that lithium recycling relies on economic issues and the profitability of lithium recovery from EV battery recycling is resolute of the raw material price for primary lithium. This phenomenon will potentially be observed in the case of electric aircraft as well.

Lithium mining and refining have great impact on the availability and quality of water (Philippot et al., 2019). In order to better understand the impact that mining and refining have on water quality, a few concepts need to be clarified. Eutrophication is defined by the Oxford dictionary as the nutrient enrichment (usually by nitrates and phosphates) of an aquatic ecosystem, such that the productivity of the system ceases to be limited by the availability of nutrients. Ecotoxicity is the quality of being poisonous to the environment. According to Philippot et al. (2019) and, Chafia and Casulli (2020), the

impact of the manufacturing of a NCA traction battery on freshwater eutrophication and ecotoxicity is driven by the presence of precious metal in the electronic components of the module housing. It is also highlighted that its impact on water scarcity is between 28 m^3 and 1800 m^3 per battery pack. Following the widespread use of lithium in LiBs, there have been rising concerns about a lithium supply crisis.

Contrary to other studies, according to Eftekhari (2019), in the past it was predicted by scientists that there would be lithium scarcity by the year 2025 even if all of the batteries available in the year 2025 was recycled. The prediction was not taken heavily up until the supply deficit which took place in the year 2015, which sparked the interest of the global community towards lithium scarcity. When it comes to mining materials, it is crucial to make a clear distinction between the term resources and reserves. For instance, lithium deposits are defined as lithium resources, recognized and projected lithium deposits are considered to be lithium reserves.

Table 1 shows presents the world's top countries in lithium reserves as of 2021. Chile remains the leading country in terms of lithium reserves as it has for the past years as well, with 9.2 million tons of Li in reserves, followed by Australia with 5.7 million tons, Argentina with 2.2 million tons and China with 1.5 million tons, as displayed in table 1.

Table 1: Lithium reserves by country - Source: USGS, 2022

Countries	Metric tons of lithium content
Argentina	2 200 000,00
Australia	5 700 000,00
Brazil	95 000,00
Chile	9 200 000,00
China	1 500 000,00
Portugal	60 000,00
United States of America	750 000,00
Zimbabwe	220 000,00

Figure 3 is an illustration of the lithium reserves data published by (USGS, 2022). Data corresponds to the year of 2021 and is updated once every year.

Figure 3: Lithium reserves by country – Source: USGS, 2022

Table 2 shows presents the world's top countries in lithium production as of 2021. Despite being the world's leader in lithium reserves, Chile is not the leading country in terms of lithium production. In 2021, Australia led the world lithium production ranking, producing 55 thousand tons of lithium, the equivalent of 0.96% of its reserves. Chile came in second place producing 26 thousand tons, an equivalent of only 0.28% of its reserves.

Table 2: Lithium production by country - Source: USGS, 2022

Countries	Metric tons of lithium content
Argentina	6 200,00
Australia	55 000,00
Brazil	1 500,00
Chile	26 000,00
China	14 000,00
Portugal	900,00
United States of America	-
Zimbabwe	1 200,00

Brazil and Portugal reached the highest reserves-production ratio, producing 1.57% and 1.50 % of their reserves respectively. Figure 4 is an illustration of the lithium mineral production data published by (USGS, 2022). Data corresponds to the year of 2021 and is updated once every year, also with a comparison with the year 2020.
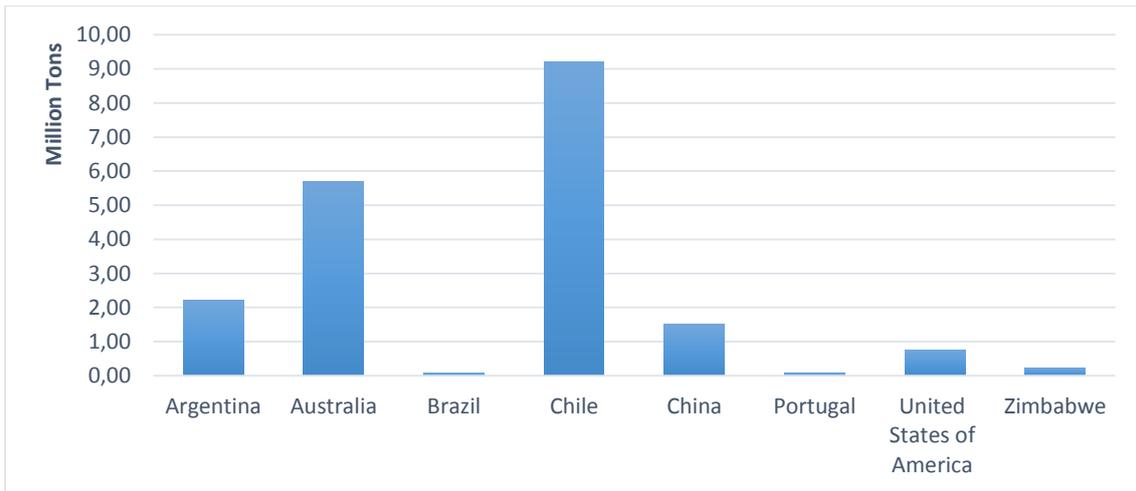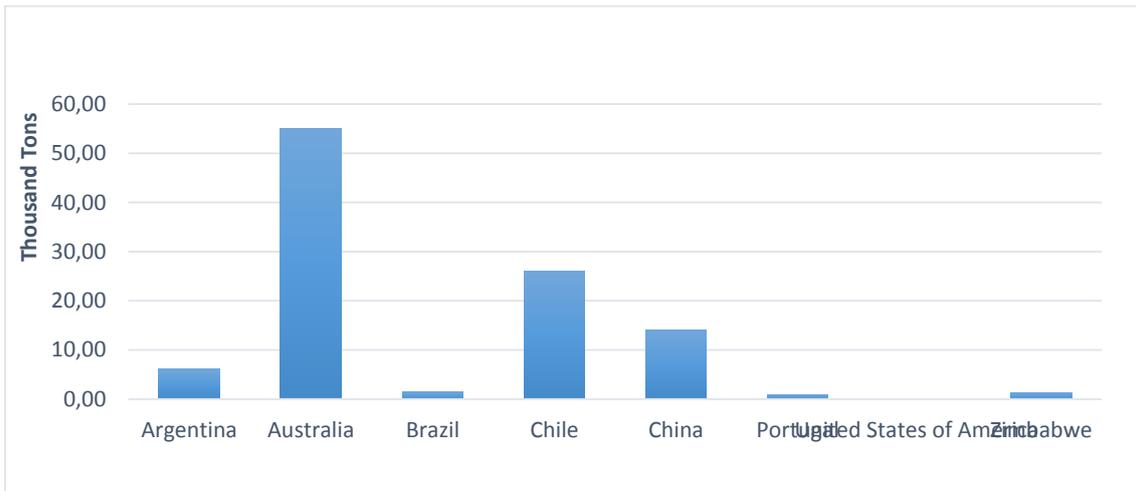
Figure 4: Lithium production by country – Source: USGS, 2022

Research developed by Georgios (2020) argues that the fast pace in which lithium demand is increasing is faster than the time needed by the supply to adapt to the needs of the consumers due to the complexity of the procedure, leading to high prices of limited resources. These kinds of disruptions are highly prejudicial to countries which their development relies strongly on lithium imports. The quality of Chile's lithium resources is remarkable. It is considered the best quality brine deposit in the world. Highly concentrated in lithium, potassium and borates (a salt in which the anion contains both boron and oxygen, as in borax) (Georgios, 2020). The Atacama deposit is the cheapest lithium resource accessible to the lithium industry due to its natural climatic conditions allowing solar evaporation, saving great amounts of energy needed for lithium exploitation. Around 22% of the total global lithium resources are located in Chile. In 2019, Chile had a production of approximately 18 thousand tons of out of the global production of 77 thousand tons in the year of 2019. Meaning that Chile produced that year about 23% of the total production in the world. Chile also seems to be right now the country with the biggest reserves, reaching 8.6 million tons (USGS, 2022).

Chafia and Casulli (2020) highlighted in their research paper "Electric Mobility and Sustainability: A Critical Analysis", that the concept of sustainable development should not be connected to electric vehicles due to the fact that they are compromising various nonrenewable natural resources and causing significant

environmental impacts for which there are no technologies to counterbalance their consequences. The same applies to electric aircraft as well. Electric vehicles have high pollution potential, damaging water, soil and humans, even at a higher degree than combustion engine vehicles in most of the cases.

2.4. Electric aircraft

Aircraft design is constantly being refined and optimized through many parameters. In the pursuit of the sustainability of the air transport industry, fuel efficiency and low emissions have somewhat reached their peak in efficiency and research has shifted towards electric aircraft. Equally, aircraft programs such as Airbus A350 and Boeing 787, for instance, have used batteries to power on-board systems. One of the main issues and biggest challenge towards the electrification of aircraft are the weight and density of lithium batteries. Figures 5, 6 and 7 display three potential architectures of future aircraft systems.
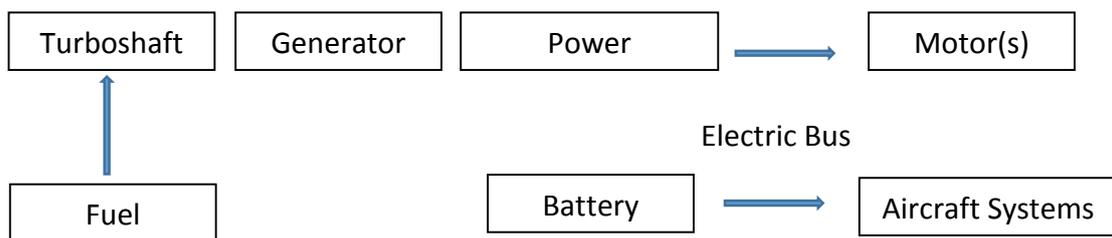
Figure 5: Diagram of a more electric hybrid aircraft potential system architecture – Source: Domone & Global, 2020
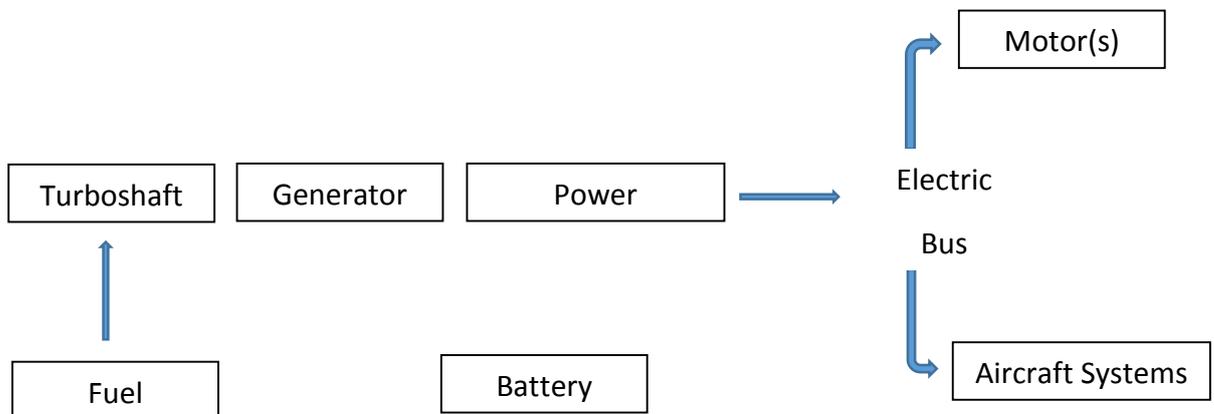
Figure 6: Diagram of a full hybrid aircraft potential system architecture – Source: Domone & Global, 2020
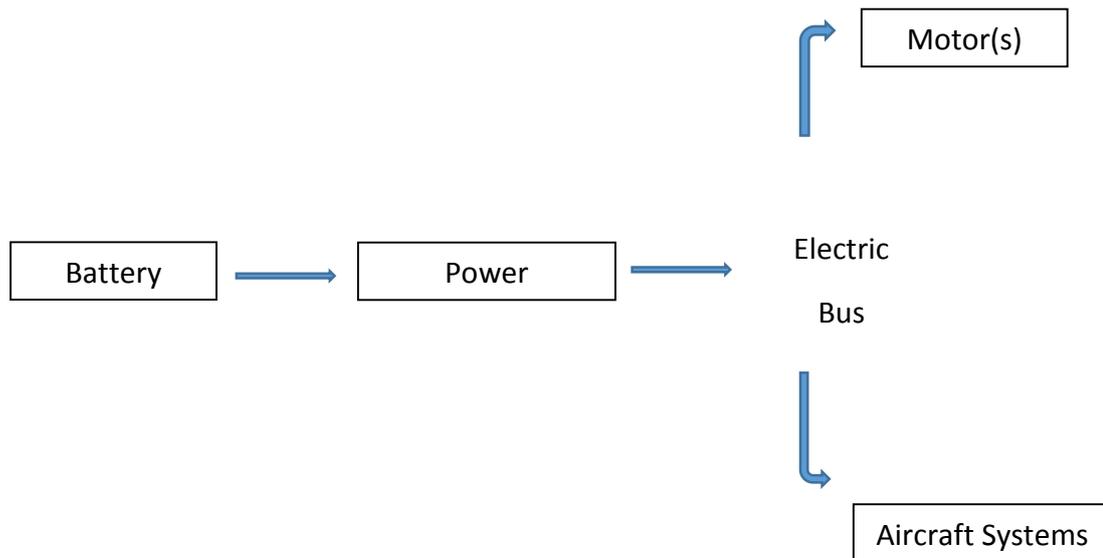
Figure 7: Diagram of an all-electric aircraft potential system architecture – Source: Domone & Global, 2020

Tay et al. (2018) on another perspective, evaluated the impact of HEA on the global air transport network. The research highlighted it could serve up to 17% of the total network. Conversely, the research exposed challenges concerning the operational infrastructure.

Zhu et al. (2019) investigated the impact of three of the most commonly proposed hybrid electric aircraft (HEA) operating regimes on lithium battery life and degradation, taking reduction in capacity and increase of direct current (DC) internal resistance with cycle number as degradation indicators. The research revealed that battery module level tests are needed to investigate the degradation modes within a module or a pack, and to identify the challenges and solutions for large-scale battery pack integration required in future hybrid electric airliners, indicating the importance of further research on the trade-off between fuel saving and battery life in future HEA. Transitioning to EVs and other means of electric transportation is beyond necessary to lower emissions, but it is also crucial to guarantee that the electricity supply comes from green resources as well. The author defends that the world's natural lithium resources are enough to support the transition to LiBs now the industry has experienced the exponentially steady increase in demand.

Another important observation made in this research was the lack of

transparency the emissions estimation methodology to understand the aggregation of the emissions. Emissions resulting from battery pack production are also unclear and difficult to estimate and analyze due to lack of accuracy regarding the battery components. Without the knowledge of the component, the estimation of total emissions' reliability is relatively low (Dillman et al., 2020).

Battery and hydrogen propulsion technologies represent the most promising paths towards a zero-carbon and zero-emissions aviation industry (Deloitte, 2021). The combination of batteries and hydrogen could significantly reduce aviation's overall climate change impact. Hydrogen is reacted in a fuel cell to provide electricity to electric motors than spin propellers or ducted fans to generate thrust. Hydrogen fuel cell electric aircraft can have range of up to 1000 km and capacity of 60-100 pax by the year 2040, with a potential of reducing up to 75% of climate impact, but increasing the flight time in 20-30% and ticket prices in 0-15%. As for battery-powered electric aircraft, electric batteries are used to power electric motors that spin propellers or ducted fans to generate thrust. The distance range could reach 500 km by 2040 and capacity of 100-120 pax, with a potential of reducing 100% of the climate impact, but increasing the flight time in 20-30% and ticket prices in 0-20%.

By 2040, higher energy costs (hydrogen), capital costs (energy storage, propulsion system) and maintenance costs (landing gear, battery replacement) of hydrogen and battery aircraft compared to conventional kerosene aircraft will lead to increased ticket prices. However, these costs are expected to decrease with the large-scale implementation of hydrogen and battery technologies (Deloitte, 2021).

The relevance of battery-powered aircraft on short routes depends on the existing rail network. Routes of 500 km represent a critical distance segment in which all modes of transport can be considered as viable alternatives. In terms of emissions, electric forms of transport, including battery-powered aircraft, clearly offer the lowest emitting alternatives, whereas kerosene airplanes are by far the most polluting mode of transport. In terms of cost, the competitiveness of cars depends on the number of passengers splitting the costs. While the travel prices for battery-powered aircraft are the highest of all modes, they remain within the range of those of kerosene airplanes and rail (and two passenger cars), but above bus prices. For distances of around 500 km, the differences in travel time between the modes of

transport is not considerable. However, air travel remains one of the fastest options and the potential development of regional air routes enabled by electric propulsion might further reduce the pre- and post-travel time necessary for air travel. The travel time of rail strongly depends on the network in place on selected routes. Journeys between cities connected by an efficient high-speed rail network might be faster by rail than by air, whereas less developed rail services could lead to longer travel times than air alternatives, and sometimes even longer than road travel. Notably, on short routes electric vehicles represent one of the best alternatives in terms of emissions and travel costs, and the advent of autonomous driving could mitigate the burden of long driving times and boost the adoption of EVs by travelers.

2.5. Socio-economic impact assessment

The socio-economic impact assessment has become a powerful tool for better understanding the implications of various projects, products or phenomenon to the society and economy which they are part of Räikkönen et al. (2016) recognized the need for a more holistic view of sustainability that integrates economic, social and environmental goals. The authors developed a study which aimed to examine different methods and techniques for evaluating the impact of sustainable investments. The study was based on research carried out in a research project towards risk-conscious investment decision-making and value creation partly funded by Tekes - the Finnish Funding Agency for Innovation - via the "New Value Creation" fund. The authors proposed, through constructive research, an assessment framework to support the integrated economic and social impact assessment of sustainable investments aimed at improving physical and socio-economic wellbeing. Their methodological approach consisted of content analysis for examination and comparison of past and present methods of investment evaluation and impact assessment and discussion of the different aspects of investment decision-making in this context. The actual framework development based on problem solving and solution building and was demonstrated in two case studies: new construction and renovation investments in affordable housing, and impact investment in sustainable development.

The identified impacts and indicators represented a combination of the insights dealing with the knowledge and future prospects of experts who participated in the research, the results of the literature review and the researchers' own experience. Despite the successful design and proposal of the framework, the credibility of the assessment is dependent on the decision-makers and stakeholders' abilities to provide reliable judgments given that the research based a lot on personal perspectives influenced by individual views of the industry, and may not cover all the important aspects of linking economic and social factors thus limiting the study. Ultimately, the study exposed therefore the need of objective indicators, stable and pertinent enough to support socio-economic impact assessments while ensuring results and insights generated from the empirical analysis of robustly defined indicators and data groups.

Consequently, it has also become quite an increasingly common tool in the air transport industry with the evolution of the sector. Many researchers have studied the socioeconomic impact of the air transport industry. As the topic has been widely approached, there have been specific trends but also challenges throughout the years. Most studies base on employment and GDP as benchmarking variables to quantify the socioeconomic impact of the air transport industry. Studies developed as early as in 1977, for instance, "The Socio-economic Impact of the Airport Upon the Community" by Alfred F. Eaton, Jr. aimed to analyze the socioeconomic impact that an airport has upon a community and to develop a method of determining that impact suitable for usage by an airport manager.

The analysis of the socio-economic impact was divided into two categories: large and medium hub airports, and small, non-hub and GA airports. Despite being one of the pioneering studies of the impact that the air transport industry has on a social and economic level, this study's scope was very limited since it only focused on one stakeholder of the industry. However, the approach was very robust due to how thoroughly the analysis of the stakeholder was conducted and the applicability of the method developed by the author which allowed a generalized use by airport managers. The lack and need of broader studies within the scope was evident, leading to further research taking it all the way to the basics and studying the impact of the industry as a whole as a way of filling the knowledge gaps and providing a wider and

closer perspective.

Obioma (2013) examined the impact of air transport to economic development via- income generation, trade and other social opportunities to Nigeria to encourage the organizations that are operating in the aviation sector in that country. The author grouped the support that the air transport industry provides to the GDP and the employment of Nigerians through four different routes: direct, indirect, induced and catalytic. Obioma gathered 2012 data from IATA, ACI, Nigerian National Bureau of Statistics and Oxford Economics and was able to quantify the monetary direct, indirect, induced and catalytic contribution of airlines, airports, ground services, and tourism to the country's GDP and to the employees. The author then explained the catalytic nature of air transport to Nigeria, arguing that it facilitates world trade, it is indispensable to the tourism, boosts productivity across the global economy, improves the efficiency of the supply chain, enables investment both into and out of countries and regions, acts as a spur to innovation and provides consumer welfare benefits to individuals.

On a social level, through qualitative data collection, Obioma argued that air transport improves quality of life by broadening people's leisure and cultural experiences, by providing a wide choice of holiday destinations around the world and an affordable means to visit distant friends and relatives. According to the author, air transport also helps improve living standards and alleviate poverty, for instance, through tourism and may provide the only transportation means in remote areas, thus promoting social inclusion. Furthermore, the author states that air transport contributes to sustainable development by facilitating tourism and trade, it generates economic growth, provides jobs, increases revenues from taxes, and fosters the conservation of protected areas. This study represented one of the milestones on the socio-economic impact assessment methodology within the air transport industry by combining a strong set of vectors and indicators into the analysis which revealed important insights and ways of improving the air transport industry of the country and related sectors as well. However, a wider set of indicators would provide a stronger analysis basis and more accurate results.

Dimitrios and Maria (2018) developed a socioeconomic impact assessment approach to quantify the socio-economic effects of air transport on regions heavily

depended on tourism, providing evidence on transport industry contribution on regional development through a specific modeling framework. Their goal was to provide an essential decision support tool for strategic decisions about planning new air transport infrastructure, when resources are limited, in order to maximize the potential of social and economic development. The impacts of air transport were comprised four categories - direct, indirect, induced and catalytic - according to previous categorizations of the effects the industry has on society and on the economy.

Their methodological approach was based on data collection and analysis for quantification of the four categories of effects. Similar to other studies, the author stated that the direct contribution of air transport sector in the national economy is measured by the direct contribution to employment (jobs created) and the contribution to GDP (income generated), and is quantified as the total number of jobs created because of the region's air transport activity. Air transport operations deal with air carriers and airport operations, aircraft maintenance, air traffic control and activities directly serving air passengers, such as check-in, security services, baggage-handling, on-site retail and catering. The jobs from this subsector represent the jobs in aviation primary firms that serve the region. The authors divided the primary firms of the air transport in aviation carries, ground-based infrastructure and aerospace manufacturing including all of the maintenance levels for aircraft systems, for airframes and also for engines. Within the aviation carriers, scheduled carriers and nonscheduled carries were considered and analyzed. Handling services, airport operators and security, and retail outlets, restaurants, airport hotels, were analyzed as ground-based infrastructure elements.

Another study around the socioeconomic impact of air transport on a country level was developed by Jason K. Sackey and Wendong Yang (2020). The authors, analyzed the contribution of air transportation to sustainable development in Ghana, considering policies towards aviation which would best promote sustainable development over the subsequent years. This study was comparatively shorter and simpler, having the data collection been conducted based on literature review, work place counts and resource people. The authors recognized that the buoyancy of the air transport industry has a broad economic impact, serving as a facilitator to other

industries through its own activities and classified its impact as direct or indirect. Furthermore, a Regressive Analysis between Ghana's GDP and Passenger throughput was conducted and data showed that Ghana's regional passenger throughput accounted for 19.80% of the general aviation market as at the highest of March 2019. Out of a whole passenger throughput of 478,621. Europe accounted for 37.90%, Middle East 10.10%, Southern Africa 8.70%, North America 4.10% and 0.20% for other regions.

Vittek et al. (2020) developed a study which aimed to research the socio-economic impacts of air transport and quantify the value it brings to the Czech Republic. The main challenge was exploring a methodology that would describe the macroeconomic and microeconomic relations within the Air transport industry and would define the directions of the market forces flow and thus the Czech Republic's value. In line with the goals of the study, the authors categorized the socioeconomic impacts of air transport as primary and secondary. The primary set of impacts comprised direct and indirect ones and the secondary one comprised induced and catalytic impacts. The study was inspired by sophistication of international standards on which it was based on.

The authors point out that ICAO established an Expert Advisory Group (EAG) under the Aviation Data and Analysis Panel (ADAP), whose task is to develop an Aviation Satellite Account (ASA) methodological framework following the System of National Accounts and even though the framework is not established yet, ICAO published a draft of it in 2019. The authors explain that the ASA methodological framework uses the International Standard Industrial Classification of All Economic Activities (ISIC) to capture and thus quantify all aviation-related activities, i.e., commercial aviation and general aviation, including all kinds of aerial work well, aviation training, airport services, maintenance and overhaul, and comes with a comprehensive sorting of companies according to the NACE. Through this paper, the authors set up ground for further development of the methodology which requires the application of analytical outputs of future periods. The paper is one of the most comprehensive and recent ones around the air transport impact assessment investigation field.

2.6. Summary

Furthermore, table 3 provides detailed information and referencing the existing literature related to each of the key themes identified throughout the literature review process.

Table 3: Literature review summarized by key theme

Themes	Related literature
Aviation and GHG emissions	Blueprint for a Green Recovery (ATAG, 2020)
	European Aviation Environmental Report (EASA, EEA, & EUROCONTROL, 2020)
	Mitigating Aviation's Long-Term Impact on Climate Change (Peeters, 2016)
	An assessment of the potential of alternative fuels for "greening" commercial air transportation (Janic, 2017)
	Life cycle assessment of air transportation and the Swiss commercial air transport fleet (Cox et al., 2018)
	Temporary reduction in global CO_2 emissions during the COVID-19 forced confinement (Le Quéré et al., 2020)
	COVID-19 and pathways to low-carbon air transport until 2050 (Gossling et al., 2021)
	Europe's future aviation landscape - The potential of zero-carbon and zero-emissions aircraft on intra-European routes by 2040 (Deloitte, 2021)
	Climate change mitigation pathways for the aviation sector (Hasan et al., 2021)
Sustainable Development Goals	Contribution of jet fuel from forest residues to multiple Sustainable Development Goals (Cavallet & Cherubini, 2018)

	The development of a framework to align the use of technologies in industries to the sustainable development goals (Spies, 2019)
	A conceptual framework for understanding the contribution of building materials in the achievement of Sustainable Development Goals (SDGs) (Omer & Noguchi, 2020)
	The importance of socioeconomic conditions in mitigating climate change impacts and achieving Sustainable Development Goals (Liu et al., 2020)
	The role of impact assessment in achieving the Sustainable Development Goals in Africa (Ibeh & Walmsley, 2021)
Lithium mineral extraction	Lithium Extraction and Utilization - A Historical Perspective (Honaket et al., 2018)
	Lithium and cobalt - a tale of two commodities (Azevedo et al., 2018)
	Modeling the potential impact of lithium recycling from EV batteries on lithium demand: A dynamic MFA approach (Ziemann et al., 2018)
	Water footprint of the manufacturing of a traction lithium-ion battery pack (Philippot et al., 2019)
	Lithium Batteries for Electric Vehicles: From Economy to Research Strategy (Eftekhari, 2019)
	Electric Mobility and Sustainability: A Critical Analysis (Chafia & Casulli, 2020)
	The Effects of Mineral Scarcity on Lithium-ion Battery (Georgios, 2020)
	Mineral Commodity Summaries 2022 (USGS, 2022)
Electric aircraft	Evaluation of the potential impacts of hybrid-electric aircraft on the global air transportation network (Tay et al., 2018)

	Investigation of Hybrid Electric Aircraft Operation on Battery Degradation (Zhu et al., 2019)
	The challenges and benefits of the electrification of aircraft (Domone & Global, 2020)
	A review of concepts, benefits, and challenges for future electrical propulsion-based aircraft (Sahoo et al., 2020)
	Review and meta-analysis of EVs: Embodied emissions and environmental breakeven (Dillman et al., 2020)
	Europe's future aviation landscape - The potential of zero-carbon and zero-emissions aircraft on intra-European routes by 2040 (Deloitte, 2021)
Socio-economic Impact Assessment	A framework for assessing the social and economic impact of sustainable investments (Räikkönen et al., 2016)
	Assessing air transport socio-economic footprint (Dimitrios & Maria, 2018)
	The Contribution of Air Transportation to the Socio-Economic Development in Ghana (Jason K. Sackey & Wendong Yang, 2020)
	Air Transport and its Socio-Economic Impacts (Vittek et al., 2020)

3. Methodology

In order to build onto the framework, the author has formulated the following research questions which will guide this study and shape a better understanding of the links and interactions between the air transport industry, electric aircraft, lithium mineral extraction and the selected SDGs for this research.

1. What is the relationship between the electrification of the air transport industry, the lithium mineral extraction industry and the UN's SDGs?

2. To what extent could the exponential increase on demand of lithium batteries accentuated by the electrification of the air transport industry affect lithium mineral extraction industry alignment and/or compliance with the SDGs?

3. What are the advantages and disadvantages of the electrification of the air transport industry to the relationship between the lithium mineral extraction industry and the SDGs?

4. What is the role of the electrification of the air transport industry in the compliance/achievement of the SDGs by the lithium mineral extraction industry?

This chapter aims to describe the methodological procedures employed to answer the research questions. The chosen research philosophy, approach, strategy, purpose and time-horizon are also explained and justified. Additionally, the challenges and limitations of the research methodology are provided.

Overall, this chapter lays out the design path of the impact assessment framework for understanding the socio-economic impact of the electrification of the air transport industry and lithium mineral extraction under a SDGs perspective.

As observed in the previous literature review section, it is increasingly primordial to investigate, predict and understand the impact of the electrification of the air transport industry. Particularly, current knowledge regarding the implications of lithium natural resources exploration and extraction remains quite limited despite the relatively fast pace of the electrification phenomenon diffusion.

This study particularly seeks to fill in the gap identified by Agusdinata et al. (2018), related to the socio-economic impact assessment of lithium mineral extraction in light of UN's sustainable development goals. Agusdinata et al. (2018) argued that in order for LiBs to be fully sustainable, the impacts along each of the life cycle stages must be

effectively addressed, including the most primary stage - lithium mineral extraction. Their study investigated in what manner the scope and focus of research in this particular area are shifting and what are the main drives of their evolution. Through a bibliometric analysis, the authors recognized that research on the socio-environmental impacts of lithium extraction has been very limited and identify research hotspots and emerging research topics:

"Instead of having the technology and regulatory environment frame the research agenda, we can let the research agenda be framed by the values and norms of sustainable development. In addition, addressing issues surrounding mining, livelihoods of communities, and development would benefit greatly by adopting broader system perspectives. These two conceptual framing frameworks articulated in the sustainable development goals (SDGs) and system-of-systems (SoS) approach respectively would in a sense 'invert' the way that it appears the research has evolved in lithium impacts and help drive the agenda with a more complete picture of impacts (Agusdinata et al., 2018)."

Another study that inspired the development of this dissertation was "The Role of Impact Assessment in Achieving the Sustainable Development Goals in Africa" developed by Christopher Ibeh from the University of Strathclyde in the United Kingdom and Bryony Walmsley from the Southern African Institute for Environmental Assessment in South Africa. Ibeh and Walmsley (2021) examined the challenges of achieving the SDGs in sub-Saharan Africa, and the role that EIA can play in achieving the SDGs in sub-Saharan Africa. Their study showed that there is a good correlation between development of EIA legislation and SDGs attainment in sub-Saharan African countries. In addition, they provided practical actions and consideration for environmental practitioners towards ensuring the alignment of SDGs to the EIA process, highlighting it as a very effective tool in evaluating the sustainability of development proposals. In this study.

In line with the identified gaps and methodologies, and under the motivation of developing a framework of SEIA which aligns with the SDGs, this study aims to present a prototype of a solution for achieving the SDGs by employing SEIA and strict adherence to regulations through data provision, conflict resolution, innovation, and positive

change, improved extreme event resilience and adaptation and using EIA as a template for broader impact assessment.

3.1. SEIA - Socio-economic Impact Assessment

According to the Socio-Economic Impact Assessment GUIDELINES published in 2007 by the Mackenzie Valley Environmental Impact Review Board, socio-economic impact assessment (SEIA) is a systematic analysis used identify and evaluate the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities. Hence, if the cited possible impacts are significant and adverse, the SEIA can assist individuals finding ways to reduce, remove or prevent them (potential changes caused – directly or indirectly, in whole or in part, for better or for worse – by industrial development activities) from happening.

While the tendency of the SEIA focusing on the avoidance of adverse impacts is acknowledged, SEIA provides aide for planning how to minimize the beneficial impacts of a development. The main goal of SEIA is to identify such impacts and finding ways to mitigate them. Therefore, the specification of how adverse impacts may interact with beneficial impacts and identification of how to manage impacts are crucial in a SEIA. It emphasizes the importance of relationships between people, culture, economic activities and the biophysical environment, and prioritizes how these relationships affect societies and economies. SEIA also aims to identify and distinguish numerous measurable impacts. The conventional process consists of answering the SEIA questions through a series of steps for identifying, assessing, mitigating and monitoring the impacts.

3.2. SEIA methodology

The SEIA methodology has not been a consensual one, having been adapted in accordance with the industry and study scope. The methodology allows the subject to mold it in order to conduct the assessment in line with the defined objectives and the

purpose of the study. In 2021, Laura Day published a modernized and holistic socio-economic impact assessment methodology.

Day (2021) proposed a holistic methodology of the impact assessment urges for the standardization of the approach for socio-economic assessment, the minimizing of subjectivity in definitions of significance and magnitude, and changes to baseline and data availability. The methodology englobes 6 stages as follows:

1. Identification of study area
2. Baseline review
3. Impact assessment
4. Identification of mitigation measures
5. Residual effects
6. Cumulative and effect interaction and monitoring the potential socio-economic impacts of a proposed development.

The first stage consists of choosing a study area suitable to the scale and the location of the proposed development. In the case of this study, the chosen area is the country Chile as mentioned in the introductory section, due to the availability of essential data compared to the remaining top lithium mining countries. Nevertheless, available data is quite limited.

Stage 2 is the baseline review. Generally, relies on secondary data collection from secondary data sources such as census data, interim data sources and reports (population and demographics, economics and employment, deprivation, education and skills, social amenity provision, recreation and tourism, and access. It is crucial to use the latest publicly-available data/information.

Stage 3 is the main stage of the impact assessment. In this stage the relevant receptors are identified and the sensitivity, impact magnitude and significance are defined. Relevant receptors should be identified basing the social and economic make-up of the study area and proposed development. Examples of receptors include: residents, business owners, locals, among many others. Receptor sensitivity is classified in 4 degrees: high, medium, low and negligible. Impact magnitude may include positive and negative changes and can be categorized as: substantial, moderate, minor and negligible. In order to analyze the significance of the impacts, a comparison of the

receptor sensitivity and the magnitude of the impact should be conducted as per table 4. It is crucial to define the sensitivities as clearly as possible in order to ensure transparency and objectivity of the analysis.

Table 4: Impact classification framework – Source: Day, 2021

Receptor sensitivity	Impact magnitude			
	Substantial	Moderate	Minor	Negligible
High	**Major**	**Major**	**Moderate**	Negligible
Medium	**Major**	**Moderate**	Minor	Negligible
Low	**Moderate**	Minor	Minor	Negligible
Negligible	Negligible	Negligible	Negligible	Negligible

In sum, if the receptor sensitivity is high or medium, and the impact magnitude is substantial or moderate, the socio-economic impact is classified as major. If the receptor sensitivity is low and the impact magnitude is substantial, moderate or minor, the socio-economic impact is classified as moderate. The remaining combinations of receptor sensitivity and impact magnitude are classified as minor or negligible.

Stages 4 and 5 are the stages of mitigation and residual effects. Following the impact assessment, feasible mitigation measures should be defined and developed for proposal/implementation. The defined mitigation measures should sufficiently reduce any adverse effect to its minimum. The final stage 6 is the stage of cumulative and effect interaction, where results can increase in strength or importance each time more is added.

3.3. SDGs – Sustainable Development Goals

According to Lewis (2016), the mining industry in general has the potential to contribute positively to all 17 of the SDGs. It can foster economic development by providing opportunities for decent employment and increased fiscal revenues, for instance.

The activities typically cause impacts on land, water, climate, flora, fauna and people. Mining can significantly impact communities and economic development. Figure 8 displays the relationship and indicative priorities between the mining industry and the 17 SDGs. Due to time, resources and workload considerations, in this study, only 4 of the SDGs which are more directly linked to the mining industry.
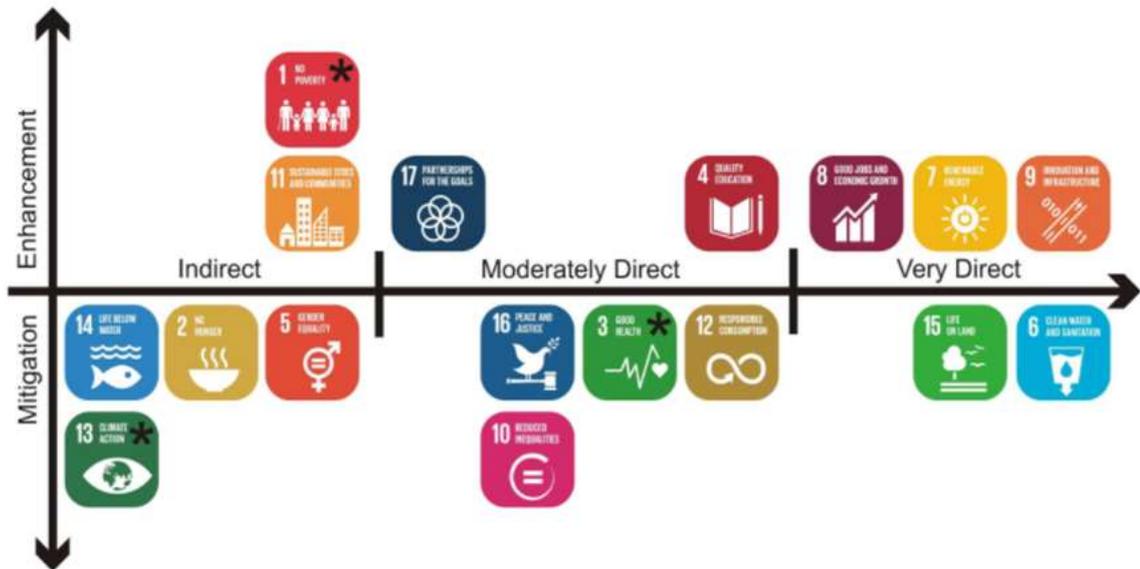
Figure 8: Mining and the 17 SDGs (Indicative Priorities) – Source: Lewis, 2016

Figure 9 shows the main issue areas for mining and each one of the 17 SDGs. The main issue areas for mining and the SDG 6 are water recycling, community involvement, water reporting and shared use. For SDG 7 are renewable energy sources, efficiency audits, shared use and reliability.

For SDG 8 they are diversification, local content, business incubators, multipliers and jobs. And for SDG 9 they are resource corridors, value added, shared use and innovation. The indicators of the cited SDGs are displayed in table 5 below.

Figure 9: Major issue areas of mining and SDGs – Source: Lewis, 2016

Table 5 provides a summary of the existing literature expressing concerns regarding each of the study's mainly focused SDGs. Concerns are mostly related to the Clean Water and Sanitation, and Decent Work and Economic Growth issues.

Table 5: SDGs 6, 7, 8 and 9, and respective targets

SDG	Targets
6. Clean Water and Sanitization	6.1. By 2030, achieve universal and equitable access to safe and affordable drinking water for all
	6.2. By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of

women and girls and those in vulnerable situations

6.3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5. By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

6.6. By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

6.a. By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6.b. Support and strengthen the participation of local communities in improving water and sanitation management

7. Affordable and Clean Energy	7.1. By 2030, ensure universal access to affordable, reliable and modern energy services
	7.2. By 2030, increase substantially the share of renewable energy in the global energy mix
	7.3. By 2030, double the global rate of improvement in energy efficiency
	7.a. By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
	7.b. By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support

8. Decent Work and Economic Growth	8.1. Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries
	8.2. Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labor-intensive sectors
	8.3. Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services
	8.4. Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programs on Sustainable Consumption and Production, with developed countries taking the lead
	8.5. By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value
	8.6. By 2020, substantially reduce the proportion of youth not in employment, education or training
	8.7. Take immediate and effective measures to eradicate forced labor, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labor, including recruitment and use of child soldiers, and by 2025 end child labor in all its forms
	8.8. Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment
	8.9. By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products
	8.10. Strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all
	8.a. Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework

	for Trade-Related Technical Assistance to Least Developed Countries

8.b. By 2020, develop and operationalize a global strategy for youth employment and implement the Global Jobs Pact of the International Labor Organization |
| 9. Industry, Innovation and Infrastructure | 9.1. Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all

9.2. Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries

9.3. Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets

9.4. By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

9.5. Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending

9.a. Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States

9.b. Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities

9.c. Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020 |

3.4. SDGs targets and indicators

According to Lewis (2016), the mining industry in general has the potential to contribute positively to all 17 of the SDGs. It can foster economic development by providing opportunities for decent employment and increased fiscal revenues, for instance. The activities typically cause impacts on land, water, climate, flora, fauna and people. Mining can significantly impact communities and economic development. Table 6 includes the selected indicators of the four chosen SDGs which are more suitable for analysis on this study.

Table 6: Original SDGs indicators VS framework adapted SDGs indicators

Goal	
Original Indicators	Adapted Indicators
6. Ensure availability and sustainable management of water and sanitation for all	
6.1.1. Proportion of population using safely managed drinking water services	6.1.1. Proportion of population in Chile with access to piped water
6.2.1. Proportion of population using safely managed sanitation services and a hand-washing facility with soap and water	6.2.1. Proportion of population in Chile with access to sanitation facilities
7. Ensure access to affordable, reliable, sustainable and modern energy for all	
7.2.1. Renewable energy share in the total final energy consumption	7.2.1. Renewable energy share in the total final energy consumption
7.3.1. Energy intensity measured in terms of primary energy and GDP	7.b.1. Energy intensity measured in terms of primary energy and GDP
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	
8.1.1. Annual growth rate of real GDP	8.1.1. Annual lithium mining sector

per capita.	growth rate of real GDP per capita.
8.3.1. Proportion of informal employment in total employment, by sector and sex	8.3.1. Proportion of lithium mining sector employment in total employment

<div align="center">**9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**</div>

9.2.1. CO_2 emission per unit of value added	9.2.1. Share of lithium mining sector's CO_2 emission per unit of value added
9.5.1. Research and development expenditure as a proportion of GDP	9.2.2. Research and development expenditure as a proportion of GDP

3.5. SDGs aligment with SEIA framework

The purpose of this study is to investigate the implications of the electrification of the air transport industry and analyze its socioeconomic impact, focusing particularly on lithium mining and exploring its influence on UN's SDGs. The study seeks to explore the relationships and interactions between the electrification of the air transport industry, the lithium mineral extraction and UN's SDGs, and develop a socio-economic impact assessment framework that takes into consideration four (4) of the SDGs which according to Lewis (2016) experience a more direct impact from the mineral extraction industry. In this specific case, the lithium mineral extraction industry represents the focus.

Building up on the foundation laid by Day (2021), the key of the alignment of the SEIA framework and UN's SDGs is basing on the chosen SDG indicators to perform the baseline review and consequently assessing the impact basing on the results of the baseline review stage. The impacts which are ultimately classified as major and moderate, are consequently worked on in the short-term mitigation measures action sheet. Similarly, the impacts which are classified as minor or negligible are worked on in the long-term mitigation measures sheet. The versatility of the methodology adaptation is the key takeaway of this research. Table 7 represents a summary of the personalized

parameters used in order to perform the impact assessment and achieve the research aims and objectives.

Table 7: SEIA framework summary table – Adapted from Source: Day, 2021

Stages	Application
Stage 1 – Identification of study area	- Chile
Stage 2 – Baseline review	- SDG 6 indicators - SDG 7 indicators - SDG 8 indicators - SDG 9 indicators
Stage 3 – Impact assessment	- Receptor: Chilean population + receptor sensitivity: high, medium, low or negligible - Impact magnitude: substantial, moderate, minor or negligible
Stage 4 – Identification of mitigation measures	- Short-term - Long-term
Stage 5 – Residual effects	- Significant adverse residual effects
Stage 6 – Cumulative and effect interaction	- Monitoring + continuous improvement

As explained above, the first stage of the methodology application is choosing the study area. consists of choosing a study area suitable to the scale and the location of the proposed development. Chile is the country that withholds almost of the world's lithium reserves and it's the world's second in terms of lithium production. Stage 2 consists of the analysis of secondary data. In this particular case, collected from the website "The World Bank – Data" (www.worldbank.org) and the statistics website "Statista" (www.statista.com).

Stage 3 is the main stage of the impact assessment. The community is defined as the receptor. The receptor sensitivity is defined according to the SDG under analysis and

the impact magnitude is classified as per the SDG indicators' data. The definition of the receptor sensitivity requires clarity because it can greatly influence the transparency and objectivity of the assessment. Following the impact assessment through the analysis of the data related to each SDG indicator and the correct filling of the impact assessment table, viable mitigation measures should be defined and developed for proposal/implementation. The defined mitigation measures should be simple, clear and achievable, but effective enough to reduce the adverse effects. In the final stage, the results can increase in strength or importance each time more factors are added.

4. Results and discussion

In this section, each one of the adapted indicators of the chosen SDG's targets are listed and analyzed following the mention order of the methodology section. The data presented in this section was collected from different statistics sources according to the indicator. Most of the data refer to the years 2020 and 2021 and prior fully available data, ensuring higher accuracy and novelty of the results given that the year 2021 and 2022 remain partial.

4.1. Study area

The chosen study area of our study is Chile, due to the availability of essential data among other top lithium mining countries in the world. Located in South America, the Republic of Chile is the southernmost country in the world. Chile covers an area of 756,096 km^2, with a population of 19.1 million as of 2020 (World Bank, 2022).
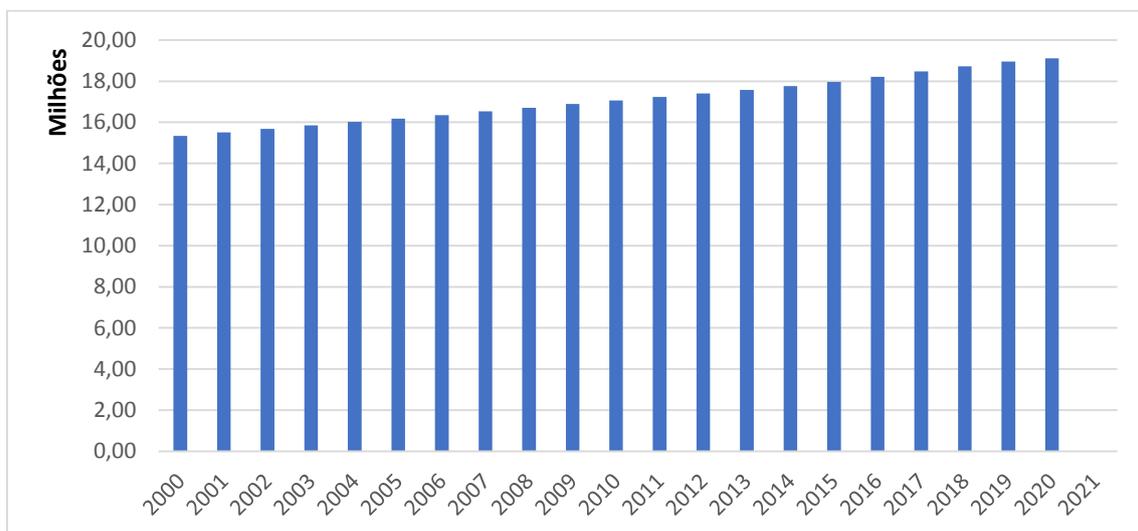

Figure 10: Total population of Chile (2000-2021) – Source: World Bank, 2022

Chile shares land borders with Peru to the north, Bolivia to the north-east, Argentina to the east, and the Drake Passage in the far south. The capital and largest city is Santiago, and its national language is Spanish. Figure 10 displays the population of Chile from the year 2000 until 2021.

4.2. Baseline review

The baseline review usually relies on secondary data collection from secondary data sources such as census data, interim data sources and reports (population and demographics, economics and employment, deprivation, education and skills, social amenity provision, recreation and tourism, and access. It is crucial to use the latest publicly-available data/information (Day, 2021).

4.2.1. SDG 6 -Water and sanitation

The main issue areas for mining and the SDG 6 are water recycling, community involvement, water reporting and shared use. The indicators analyzed for this SDG are 6.1.1. (Proportion of population using safely managed drinking water services) and 6.2.1. (Proportion of population using safely managed sanitation services).
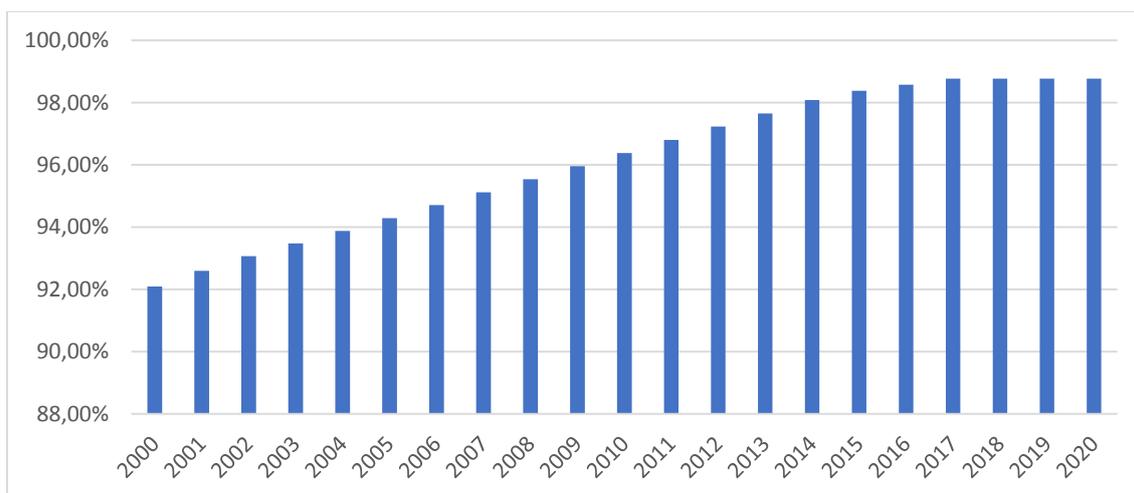
Figure 11: Population using safely managed drinking water services (2000-2020) – Source: World Bank, 2022

In this subsection, in order to analyze the adapted indicators of the SDG 6 – water and sanitation. For this analysis, we collected all the available data from the year 2000 up until 2020. The population using safely managed drinking water services has increased almost 7%. In the year 2000, approximately 92.10% of Chile's population had access to safely managed drinking water services.

By 2010, the percentage of population with access to safely managed drinking water services had reached approximately 96.40%. Despite the remarkable increase in the between the year 2000 and 2010, the percentage stagnated in 98% from 2014 onwards. Figure 11 illustrates the percentage of population in Chile with access to safely managed drinking water services between the year 2000 and 2020. The data can be consulted in the appendix section.
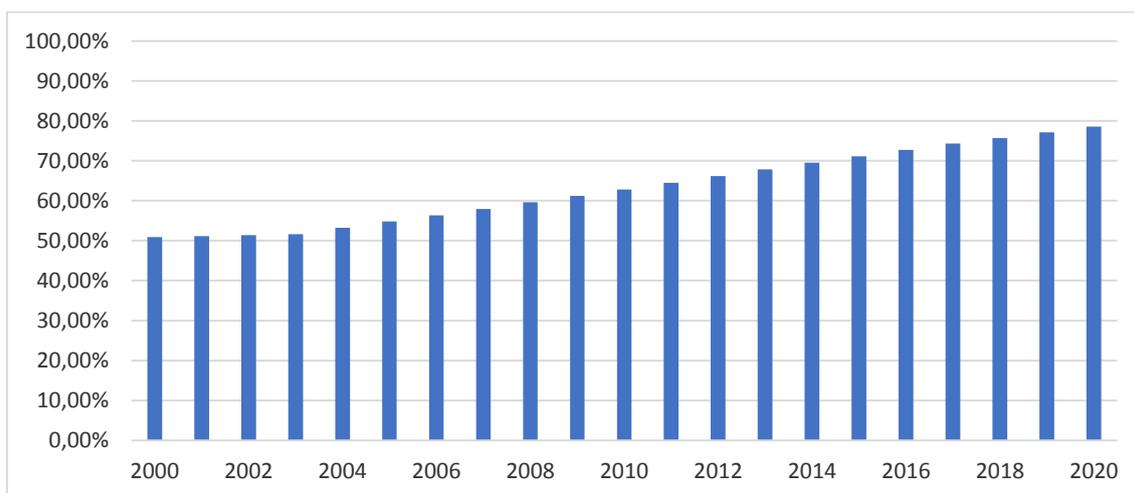
Figure 12: Population using safely managed sanitation services (2000-2020) – Source: World Bank, 2022

In regards to the sanitation, the percentage of population using safely managed sanitation services increased almost 29% from the year 2000 to 2020. In the year 2000, approximately 50.90% of Chile's population had access to safely managed sanitation services. In 2010, the percentage of population with access to safely managed sanitation services was of approximately 62.90%. By 2020, the percentage had reached 78.60%. Figure 12 illustrates the percentage of population in Chile with access to safely managed sanitation services between the year 2000 and 2020. The data can be consulted in the appendix section.

4.2.2. SDG 7 – Affordable and clean energy

The main issue areas for SDG 7 are renewable energy sources, efficiency audits, shared use and reliability. Renewable energy consumption is the share of renewable

energy in total final energy consumption. For this analysis, we collected all the available data from the year 2000 up until 2018.

The average percentage of renewable energy of the total final energy consumption from the year 2000 until up to date in Chile is 29.48%. We can observe oscillations in the data throughout the years. Increasing from the year 2000 until 2002, and slightly increasing between 2003 and 2006. An increase is also observed from the year 2007 up until 2009, decreasing again from 2013 up until 2018.

The maximum percentage within this time scope under analysis was of 33.07% correspondent to the year 2002 and the minimum was of 24.11% correspondent to the year 2017.
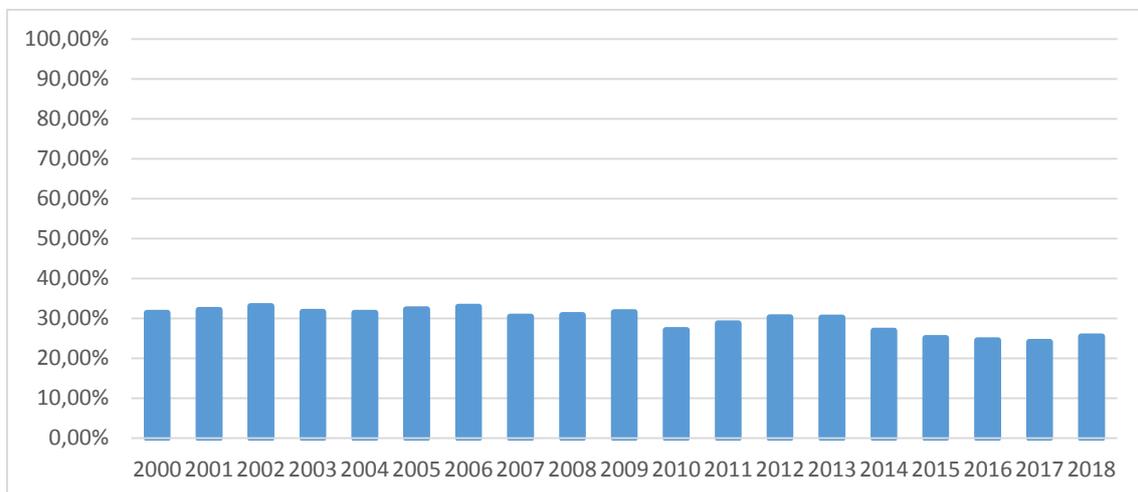
Figure 13: Renewable Energy Consumption (2000-2018) – Source: World Bank, 2022

The oscillations can be associated to the increase of access to electricity. For instance, in 2002, approximately 97.30% of Chile's population had access to electricity. By 2017, the percentage had reach approximately 99.70%. The 100% mark was reached in the following year. Figure 13 illustrates the percentage of renewable energy consumption out of the total final energy consumption between the year 2000 and 2018. The data can be consulted in the appendix section. Figure 14 illustrates the percentage of population in Chile with access to electricity between the year 2000 and 2020. The data can be consulted in the appendix section.
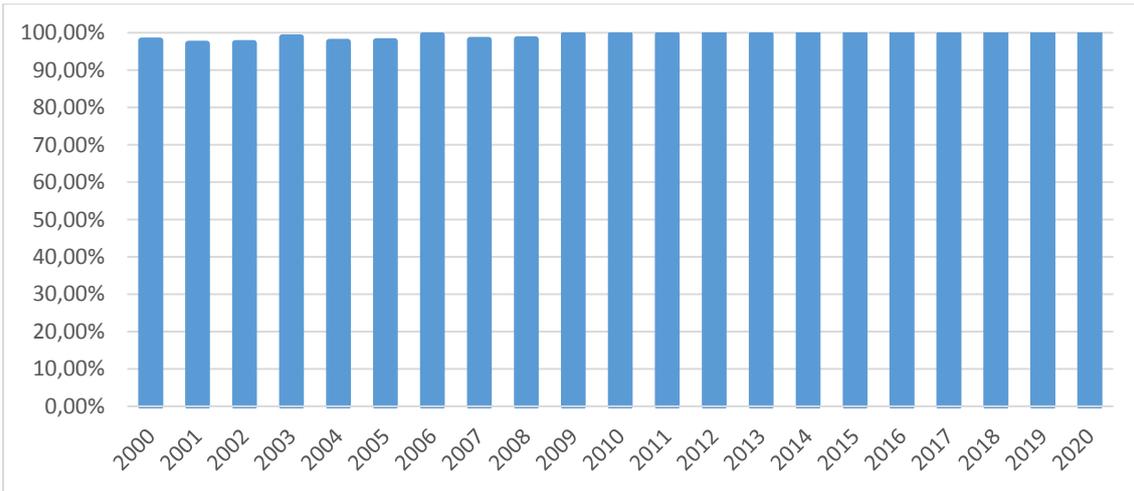
Figure 14: Access to electricity (2000-2020) – Source: World Bank, 2022

Energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured at purchasing power parity. Energy intensity is an indication of how much energy is used to produce one unit of economic output. Lower ratio indicates that less energy is used to produce one unit of output.

The average energy intensity level of primary energy in Chile averaged 3.78% between the year 2000 and 2019. In general, it has decreased over the years. The highest level was registered in the year 2000, and the lowest was registered in 2015. Figure 15 illustrates the energy intensity level of primary energy between 2000 and 2021. The data can be consulted in the appendix section.
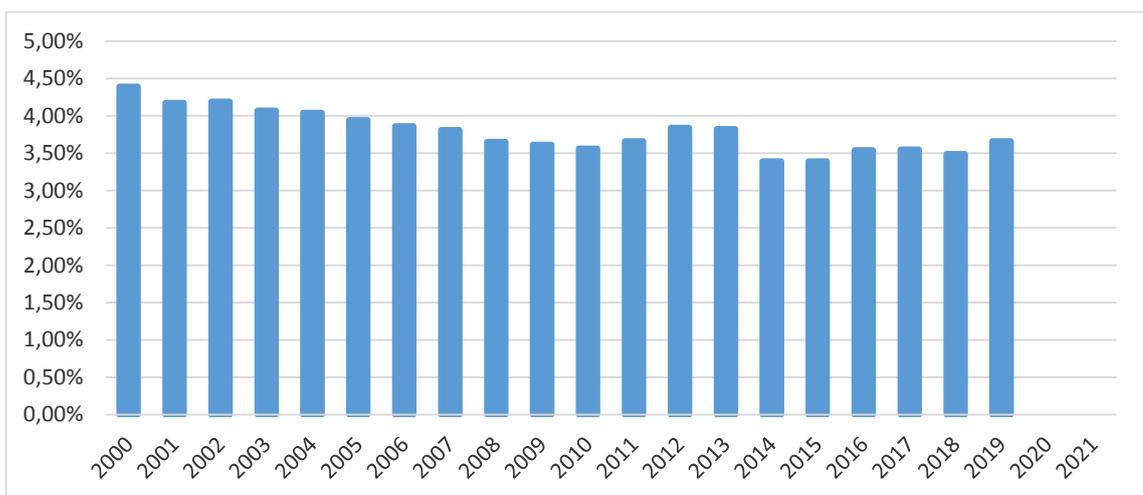
Figure 15: Energy intensity level of primary energy (2000-2021) – Source: World Bank, 2022

4.2.3. SDG 8 – Decent work and economic growth

The main issue areas for SDG 8 are diversification, local content, business incubators, multipliers and jobs. The indicators analyzed for this SDG are 8.1.1. (Annual lithium mining sector growth rate of real GDP per capita) and 8.3.1. (Proportion of lithium mining sector employment in total employment).
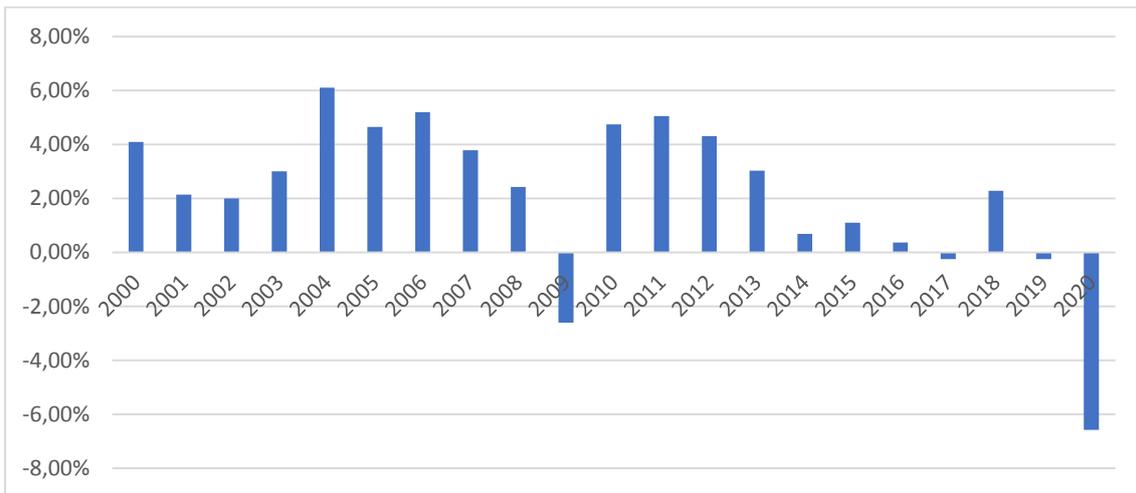
Figure 16: GDP per capita growth (2000-2020) – Source: World Bank, 2022

In order to review the adapted SDG's indicators 8.1.1 and 8.3.1, more than one set of data has to be analyzed due to unavailability of direct data. First, we analyze Chile's GDP per capita growth. GDP per capita growth is the annual percentage growth rate of GDP per capita based on constant local currency. Between the year 2000 and 2020, Chile's GDP grew approximately annually 2.20% per capita on average. Figure 16 illustrates the percentage of GDP per capita growth between 2000 and 2020. The data can be consulted in the appendix section. The maximum percentage of GDP per capita growth registered in that period of time was of 6.10% in 2004, and the minimum was of approximately -6.60% in 2020 due to the pandemic. Nevertheless, Chile's average annual GDP per capita growth has been of approximately -0.50%.

Furthermore, it is also necessary to analyze the Chile's mining share of GDP. Between the year 2010 and 2020, the average mining share of Chile's GDP was of 11.20%. The maximum mining share of GDP was of 16%, registered in 2010, and the minimum was of approximately 8.10% in 2016. For this data set, the data available is relatively limited, not covering the period of 2000-2010. The lithium mining sector is the

second biggest mining sector in Chile. Figure 17 illustrates the mining share of GDP between in 2010 and 2020. The data can be consulted in the appendix section. Chile's average annual GDP per capita growth has been of approximately -0.50%. Graphic 8 illustrates the percentage of mining share of GDP in Chile between 2010 and 2020. The data can be consulted in the appendix section.
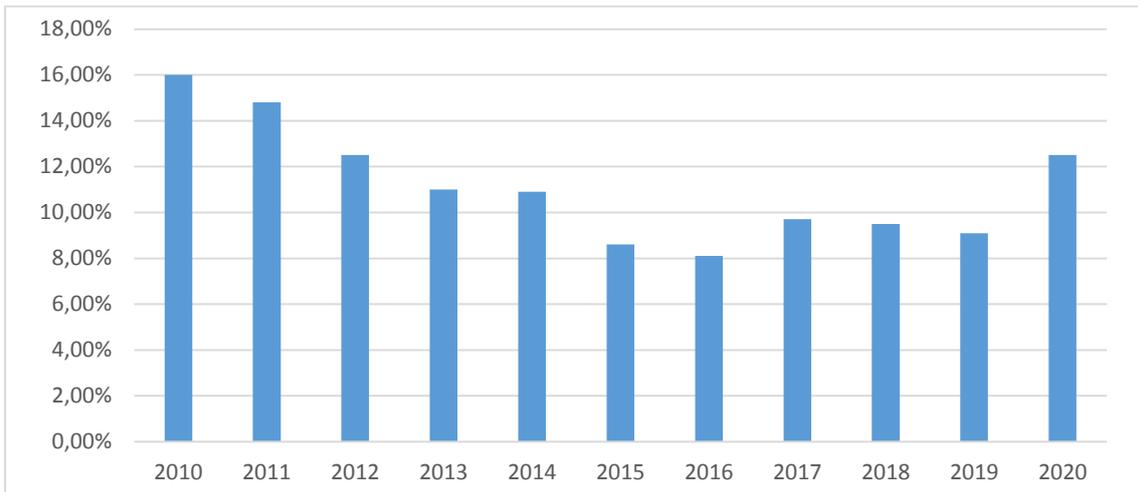
Figure 17: Mining share of GDP (2010-2020) – Source: Statista, 2022

Furthermore, the number of employees in the mining sector is analyzed. The average number of employees in Chile's mining sector as of approximately 227 thousand employees. Figure 18 illustrates the number of employees in the mining sector between in 2010 and 2020. The data can be consulted in the appendix section.
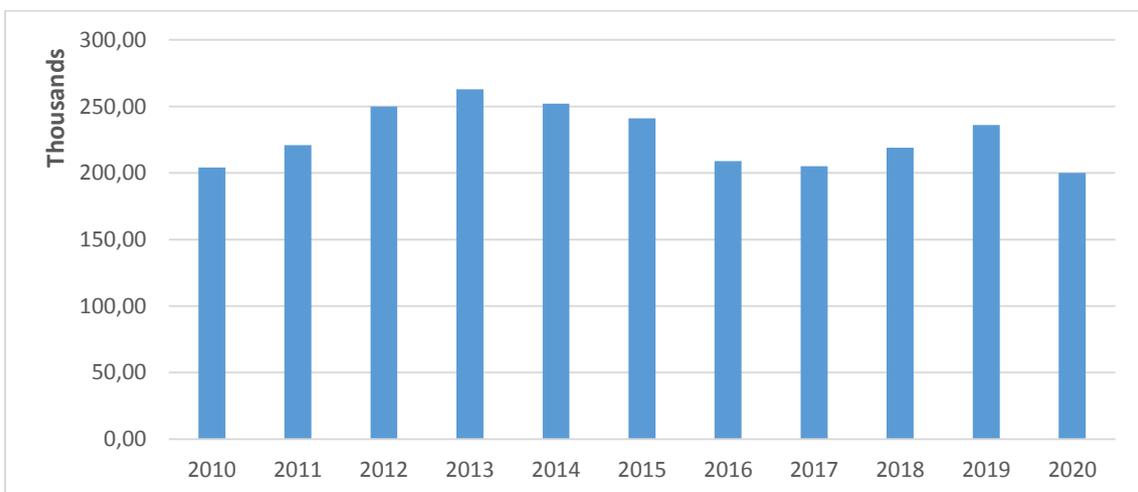
Figure 18: Number of employees in mining sector (2010-2020) – Source: Statista, 2022

The maximum number of employees in the sector was registered in 2013 (263,000), and the minimum number of employees in the sector was registered in 2020, which is the latest data available for analysis (200,000).

Excluding U.S. production, worldwide lithium production in 2021 increased by 21% to approximately 100 thousand tons from 82,500 tons in 2020 in response to strong demand from the lithium-ion battery market and increased prices of lithium (USGS, 2022). Global consumption of lithium in 2021 was estimated to be 93 thousand tons, a 33% increase from 70 thousand tons in 2020. Owing to the resurgence in demand and increased prices of lithium in 2021, established lithium operations worldwide resumed capacity expansion plans which were postponed in 2020 in response to the global COVID-19 pandemic (USGS, 2022).

Conversely, migration in Chile has been rising in the past years. Net migration is the net total of migrants during the period, that is, the total number of immigrants less the annual number of emigrants, including both citizens and noncitizens. The available date is of five-year estimates (World Bank, 2022). The latest estimates available are of 2017, when the number of migrants was of approximately 560 thousand. Figure 19 illustrates the net migration between in 2000 and 2021. The data can be consulted in the appendix section.
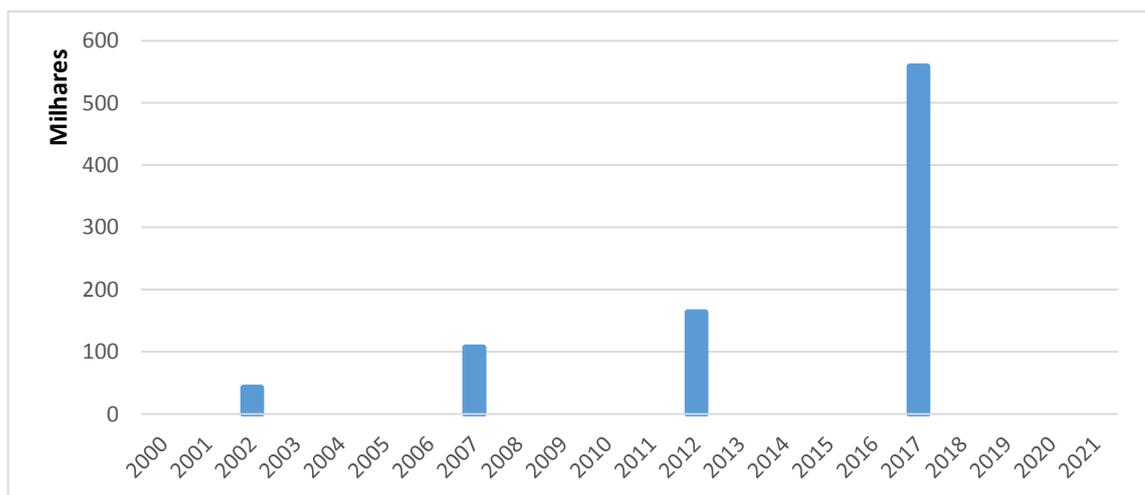
Figure 19: Net migration (2002-2021) – Source: World Bank, 2022

The three variables analyzed above, give us a more thorough vision of the state of Chile in terms of SDG 8. The correlation between these variables

4.2.4. SDG 9 – Industry, innovation and infrastructure

Finally, the main issue areas for SDG 9 are resource corridors, value added, shared use and innovation. The indicators analyzed for this SDG are 9.2.1. (Share of lithium mining sector's CO_2 emission per unit of value added) and 9.2.2. (Research and development expenditure as a proportion of GDP). The available data set on the World Bank Data website for analysis of the CO_2 emissions is quite limited and outdated. The latest data available refers to the year 2018. Here the CO_2 emissions (metric tons per capita) are defined as carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement, including carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring (World Bank, 2022).

Between the year 2000 and 2021, Chile emitted an average of 4 metric tons of CO_2 per capita. The smallest amount of emissions was registered in 2001, approximately 3.10 metric tons, while the highest amount of emissions was registered in 2017, which reached approximately 4.70 metric tons.
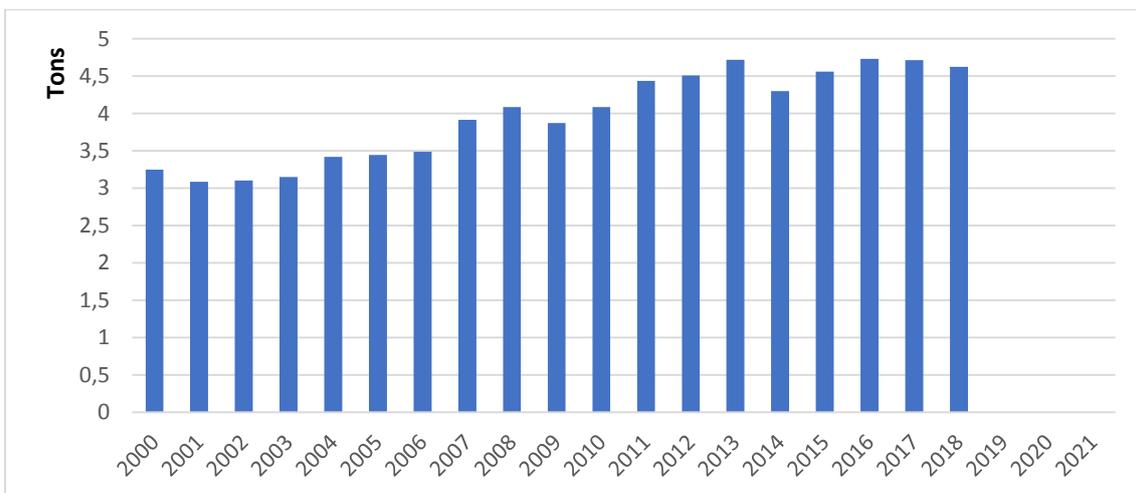
Figure 20: CO_2 emissions (2000-2021) – Source: World Bank, 2022

The emissions oscillations rounding 4 metric tons can be attributed to the increase in manufacturing, including lithium production, and to improvements on the fossil fuels efficiency. Figure 20 illustrates Chile's CO_2 emissions in metric tons per capita between in 2000 and 2021. The data can be consulted in the appendix section.

Research and development expenditure (% of GDP) are the gross domestic expenditures on research and development (R&D), expressed as a% of GDP. It is the share of the country's GDP which is invested into research and development of multiple areas, including the achievement of SDGs' targets and improvement of their indicators. In Chile's case, the available data set is limited between the year 2007 and 2017. Figure 21 illustrates Chile's research and development expenditure between 2000 and 2021. The data can be consulted in the appendix section.
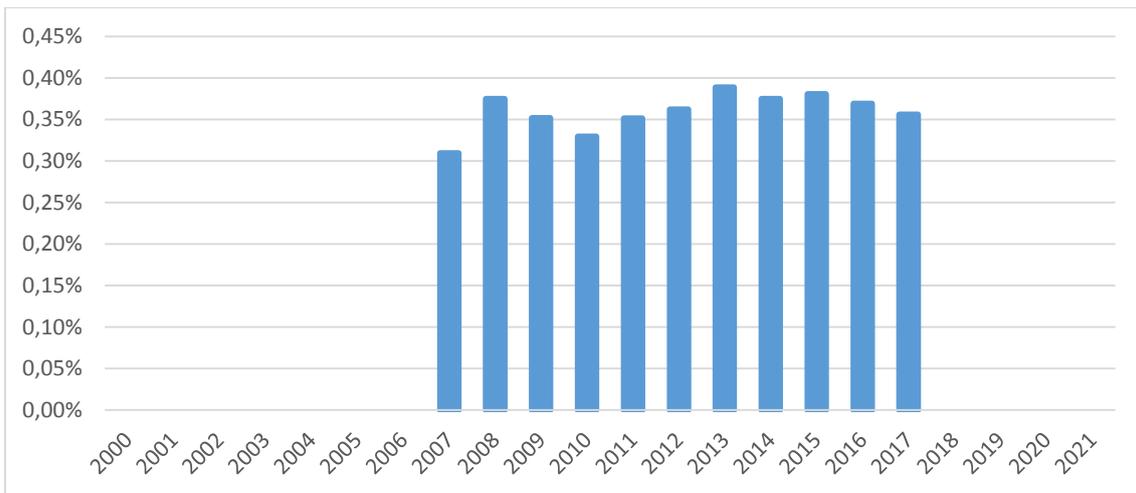
Figure 21: Research and development expenditure (2007-2017) – Source: World Bank, 2022

In the 10-year period under analysis, the percentage of Chile's GDP allocated to research and development remained between 0.30% and 0.40%, averaging 0.36%. The highest percentage was of approximately 0.39%, which was allocated in 2013, and the lowest percentage was of approximately 0.31%, allocated in 2007.

4.3. Impact assessment

. The impact assessment is the main stage of the assessment process. In this subsection the relevant receptors are identified and the sensitivity, impact magnitude and significance are defined. Relevant receptors should be identified basing the social and economic make-up of the study area and proposed development. In this study's particular case, the relevant receptor is narrowed to the Chilean population and

community. The impact magnitude is defined in function of the baseline review results and insights.

Water and sanitation are highly sensitive to the local community, and the mismanagement or neglect of proper water management services could substantially impact the local community as well. Although the country seems to be on track to achieve UN's water and sanitation SDG targets, the impact of this SDG onto the community on a lithium mining perspective fueled by the increase of EVs and adoption of electric aircraft can be monumental due to the high amount of water used in lithium production processes.

Therefore, although the available data results are positive, the issue it not straightforward, because we lack the information regarding how much water is used and wasted by the production companies at the lithium mining sites which are also dry and arid areas with water access issues. Under these circumstances, concerns can be raised regarding the achievement of the water target 6.1. - By 2030, achieve universal and equitable access to safe and affordable drinking water for all – given that the lithium mining activities have significantly negative influence on the water access and quality in the lithium mining regions, as reviewed in the literature.

Affordable and clean energy falls into the medium receptor sensitivity category and has a moderate impact on the daily lives of the community members, given that as of 2020, 100% of the population had access to electricity, achieving the target 7.1. ten years ahead of the target's timeline. The data analyzed for this SDG, reveals a relatively high percentage of renewable energy consumption out of the total final energy consumption. For instance, the average percentage of renewable energy consumption out of the total final energy consumption in Portugal has been of only approximately 24% in the past 20 years (World Bank, 2022).

The target 7.2. seeks to increase substantially the share of renewable energy out of the total energy consumption, and although the percentage has not been steady in the past years (2013-2015), the prospects for increase are very achievable and following the momentum that has been set from the year 2000 which is the first year of analysis, the target can be achieved. Nevertheless, it also raises uncertainties due to the lack of a specific target percentage to be aimed for and to be achieved in order to classify the

process of achievement of this SDG which is also very connected to environmental impacts.

SDG 8 can be divided into decent work falls into the high receptor sensitivity category and economic growth which falls into the medium receptor sensitivity, given that decent work not only affects the population more directly, but also plays a significant role on their quality of life and buying power. Within the analyzed period of time, Chile's GDP annual growth per capita did not surpass 6.10%, and registered falls in 2009, 2017, 2019 and 2020. The mining share of the GDP hit its lowest percentage in 2016 (8.10%), preceding the GDP drop of 2017.

Through the analysis of the mining share of GDP, we can observe that Chile's economy has a strong foundation on the mining industry, specially of copper and lithium. Despite the decrease of the percentage over the years, the share has been increasing again, following the trend of rise in lithium demand and dissemination of EVs. Chile still has to improve its lithium production capacity in order to counteract the rise in demand, while maintaining its leadership as the world's biggest in terms of lithium reserves and deposits.

Following the rise of demand and increasing need of lithium production, it is intuitive that increases of workforce will be necessary, therefore generating more jobs. Conversely, the number of employees working in Chile's mining sector has not been steady over the years, and actually seems to be decreasing. Within the analysis timeframe, 2020 was the year which registered the lowest number of employees working in the mining sector, including of lithium extraction.

It is important to take into consideration that migration has been rising over the years, with significantly high growth rates. Here prevails the need of workers for the mines, the population growth, but decrease in the number of workers in the mines and increase of migration due to lack of conditions and water conditions in the mining extraction areas. Overall, it is notable that the impact of the increase of lithium production will have on the communities is positive, and will go hand-to-hand with the indicators analyze.

Industry, innovation and infrastructure (SDG 9) is also subjective, based on the performed baseline review. Its receptor sensitivity can either be classified as high or low, but is balanced with minor impact magnitude or substantial impact magnitude. The

analysis revealed that Chile's CO_2 emissions have been rising in the past years, having only slightly decreased 0.40% from 2013 to 2014. The average yearly emissions are of 4 metric tons, and despite the big dimension of the country's mining industry, it is unclear how much of its emissions can be attributed to the mining industry, specially of lithium. This is concerning, raising speculations regarding how much will the emissions increase with the increase of demand of lithium for EVs and specially for electric aircraft after during their manufacturing process up until their implementation and generalization.

Another concerning number on this SDG's baseline review is the percentage of GDP which is allocated to research and development by Chile's government. In order to predict and mitigate the changes and adjustments that the advent of the electrical future will bring, it seems necessary to begin investing more into the achievement of this SDG and to prepare for the potential changes which lie ahead. Following the discussion of the results of the indicators of the four SDGs under analysis, the result of correspondence between the receptor sensitivity and impact magnitude in function of the SDGs is summarized on table 8.

Table 8: Lithium mining SDGs impact classification

Receptor sensitivity	Impact magnitude			
	Substantial	Moderate	Minor	Negligible
High	SDG 6	SDG 8	SDG 9	-
Medium	SDG 8	SDG 7	-	-
Low	SDG 9	-	-	-
Negligible	-	-	-	-

After reviewing and analyzing the sensitivities and impact magnitudes, and having the base map which provides the state of the SDGs in Chile, a SWOT analysis is conducted, pointing out each the SDGs analyzed in the baseline review as a strength, weakness, opportunity or threat. Forbes (2022) explains that SWOT analysis is a framework used in a business's strategic planning to evaluate its competitive positioning in the marketplace.

The analysis looks at four key characteristics that are typically used to

compare how competitive the business can be within its industry. In this case, the SWOT analysis is used to evaluate the electrification of the air transport industry in relationship with the 4 focus SDGs (6, 7, 8 and 9). Strengths and Weaknesses focus internally, while Opportunities and Threats look at things going on externally. Strengths are internal positives that can be controlled and that often provide with a competitive advantage. Weaknesses are an adverse internal attribute that negatively takes away from the strengths. Opportunities are an external factor that provides promise or is likely to contribute to success. And threats are external factors that cannot be controlled and could impact success (Forbes, 2022).

Basing on the analysis results' discussion above, the SDGs which represent Strengths within the lithium mining in Chile in prospects of the electrification of the air transport industry are SDG 7 – Affordable and Clean Energy and SDG 9 – Industry, Innovation and Infrastructure. These strengths also represent opportunities, as the commitment towards these areas and the achievement of these SDGs can bring great benefits to the local communities and the country as a whole.

Due to their contradictory results, SDG 6 – Clean Water and Sanitation and SDG 8 – Decent Work and Economic Growth are categorized as weaknesses. Their achievement is more at risk and could bring significantly negative consequences to the country and its economy. For the same motives, they can also be categorized as threats to the achievement of the targets, deserving special attention from all the involved stakeholders, specially from the local and country's governments, from the mining industry companies and their partners, and specially from the local communities which are the most relevant "receptors" of the consequences.

The communities should also be encouraged to raise more awareness and seek for ways in which they can also contribute for the mitigation of these posing threats. Figure 22 represents a diagram of the SWOT analysis performed above.
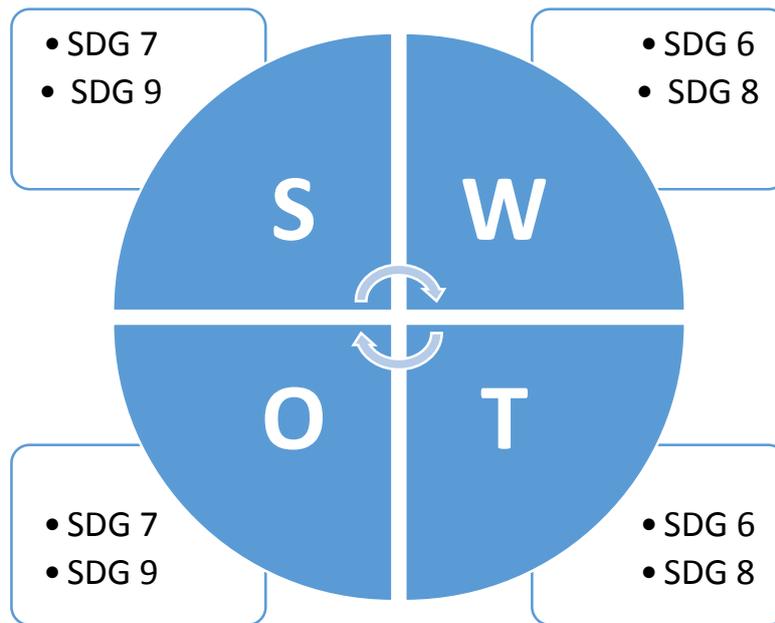
Figure 22: Diagram of SWOT analysis

5. Conclusion, limitations and recommendations

The electrification of the air transport industry may take more time than expected. The process, including the increase of the demand of lithium mineral for batteries' production could be more complex and not as straightforward as it might be idealized, especially with the environmental laws and SDGs to be achieved. The advent of electric aircraft could substantially change the lithium mineral extraction market and industry, and will consequently influence the achievement of UN's SDGs not only by Chile, but also the remaining top lithium production countries not analyze in this study. These three elements will be more than ever dependent on each other and influence one another. The increase of lithium batteries' demand could have both positive and negative effects on the compliance of the SDGs, making the monitoring of their effects crucial to the compliance. This will demand more transparency from all the stakeholders involved, especially the production companies, and the openness of related specific and important data.

There are innumerous concerns regarding the feasibility and reliability of the electrification of the air transport industry. Nevertheless, through the developed framework and the analysis performed in this study, it is hard to make accurate conclusions regarding the advantages of disadvantages that the rise of electric aircraft

will have on the lithium mineral extraction industry. For instance, while it will generate more jobs, the environmental impacts on the local areas could also incentive the increase of migration. Also, there is a high potential of increase of GHG emissions triggered not only by the production of lithium but also if the charging methods of the batteries are not transformed into environmentally-safe methodologies from clean energy sources. In order for the electric aircraft to serve their emissions mitigation mission and for the SDGs to be achieved not only until the year 2030 but also beyond, the concerns raised throughout this study should be timely and properly considered and addressed.

On a social level, the rise of electric aircraft and increase of demand and production of lithium batteries will negatively impact the quality of the water used daily by local communities in the mining areas, affecting their quality of life and consequently increasing migration. It has a high potential of increasing of emissions, especially if not rigorously monitored, which could affect the health of its citizens, especially the ones neighboring the mining areas and sites. Nevertheless, on a positive note, the changes will strengthen and improve access and adherence to sustainable sources of energy, and has the potential of raising more awareness towards good practices in mining, mitigation of effects on social groups and improvement of coping measures.

On an economic perspective, the rise of electric aircraft and increase of demand and production of lithium batteries will positively affect the country's economy, with the potential of growing its GDP each year and generating more employment which could not only serve the local community but also attract national and international professionals to the industry and the areas, opening room for local development. However, further investment in the industry and its yearly production capacity could be crucial for a steady and sustainable economic development and improvement of the communities' quality of life.

The biggest challenge faced throughout the development of this research at first was literature associating the socio-economic impact assessment methodology to the modern concept of UN's SDGs. Nevertheless, this also contributed to the definition of the knowledge gap in need of being filled within the study area. Deeper into the research process, the greatest challenge revealed to be data availability, and given that the methodology used generally relies on secondary data, it was a challenge to be

overcome, which also conditioned a good number of methodologic choices throughout the research development as well. Another limitation was also the inability to include all of the SDGs, their targets and respective indicators into the baseline review and analysis, given that it would extend the study into dimensions which go beyond the regulations set for the public proofs presented here.

Future research could focus on gradually introducing more to all of the indicators of the 4 SDGs analyzed in this study. On a further advanced level, all of the SDGs could be included in the baseline review section of the methodology, and gradually work with smaller data timeframes (5-10 years only) and consolidate the methodology into a simplified yearly analysis tool for continuous monitoring of the SDGs indicators. Furthermore, the author also recommends the investigation of the socio-economic impact of electric aircraft in small routes, which due to the short range of the aircraft could be the best markets to begin with the implementation of electric aircraft. Future research could also focus on correlating the datasets of each of the SDG indicators with each other in order to obtain further insights regarding the issue through cross-match of the information. Another important angle of investigation is the socio-economic impact of electric aircraft on aviation's training, education, hierarchy and professional satisfaction and empowerment of older staff members.

Regarding the dataset, as stated above in the study limitations subsection, specific, available and reliable data regarding the mining sector, not limited to lithium mining, is very scarce and hard to find. In order to effectively monitor the potential effects of electric aircraft laws and regulations of the mining sector in Chile and other countries. Data availability and openness is crucial for accurate and inclusive analysis, and for further developments and continuous improvement. It is also recommended to apply the methodology developed in this study and complement the methodology with interviews of specialists from each of the SDG focus areas and to local communities in order to gather a wider amount of information and be able to get more insight of the real issues that the communities deal with on a daily basis, and how something that can seem foreign to their reality (electric aircraft) is actually impacting their daily routines and quality of life in the pursuit of a better future for all.

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7. Appendix

Appendix 1 – Total population of Chile (2000-2020)

Year	Total Population
2000	15,342,350.00
2001	15,516,112.00
2002	15,684,413.00
2003	15,849,649.00
2004	16,014,972.00
2005	16,182,713.00
2006	16,354,507.00
2007	16,530,201.00
2008	16,708,255.00
2009	16,886,184.00
2010	17,062,531.00
2011	17,233,584.00
2012	17,400,359.00
2013	17,571,511.00
2014	17,758,969.00
2015	17,969,356.00
2016	18,209,072.00
2017	18,470,435.00
2018	18,729,166.00
2019	18,952,035.00
2020	19,116,209.00

Appendix 2 – Population using safely managed drinking water services (2000-2020)

Year	Percentage (%)
2000	92.09302425
2001	92.59391052
2002	93.07063436
2003	93.47617698
2004	93.88457656

2005	94.29474878
2006	94.70764542
2007	95.12258641
2008	95.54008597
2009	95.95954891
2010	96.380973
2011	96.80474805
2012	97.23040346
2013	97.65809925
2014	98.08776264
2015	98.38247341
2016	98.57763407
2017	98.77024025
2018	98.77136341
2019	98.77136217
2020	98.77136473

Appendix 3 – Population using safely managed sanitation services (2000-2020)

Year	Percentage (%)
2000	50.93020344
2001	51.18679267
2002	51.43395989
2003	51.65471264
2004	53.21928976
2005	54.79560816
2006	56.3840428
2007	57.98429897
2008	59.59664186
2009	61.22076212
2010	62.85662723
2011	64.50452638
2012	66.16412487
2013	67.83556426
2014	69.51881798
2015	71.18451893
2016	72.75744191
2017	74.37180759
2018	75.70739056
2019	77.15227438
2020	78.60140201

Appendix 4 – Renewable energy consumption (2000-2018)

Year	Renewable Energy (%)
2000	31.36330032
2001	32.1473999
2002	33.0705986
2003	31.61510086
2004	31.43560028
2005	32.26319885
2006	32.90829849
2007	30.46479988
2008	30.82929993
2009	31.52700043
2010	27.0442009
2011	28.79179955
2012	30.30500031
2013	30.22970009
2014	26.94610023
2015	25.06509972
2016	24.55439949
2017	24.10740089
2018	25.46069908

Appendix 5 – Access to electricity (2000-2020)

Year	Access to electricity (% of population)
2000	97.93869019
2001	97.11580658
2002	97.28368378
2003	98.78232574
2004	97.60608673
2005	97.76531219
2006	99.36811066
2007	98.09201813
2008	98.26486969
2009	99.59365845
2010	99.53839111
2011	99.5881958
2012	100
2013	99.59999847
2014	100
2015	99.71484375
2016	100
2017	99.69999695

Year	
2018	100
2019	100
2020	100

Appendix 6 – Energy intensity level of primary energy (2000-2019)

Year	Energy Intensity Level of Primary Energy (%)
2000	4.39
2001	4.17
2002	4.19
2003	4.07
2004	4.04
2005	3.94
2006	3.86
2007	3.81
2008	3.65
2009	3.61
2010	3.56
2011	3.66
2012	3.84
2013	3.82
2014	3.39
2015	3.39
2016	3.54
2017	3.55
2018	3.49
2019	3.66

Appendix 7 – GDP per capita growth (2000-2020)

Year	GDP per capita growth (annual%)
2000	4.094314573
2001	2.146176048
2002	2.000585088
2003	3.005876123
2004	6.102812658
2005	4.646759137
2006	5.200380038
2007	3.790320755
2008	2.42625274
2009	-2.60145285
2010	4.750242103

2011	5.057708365
2012	4.309193989
2013	3.031573491
2014	0.692522609
2015	1.105984398
2016	0.372098731
2017	-0.247251359
2018	2.281121035
2019	-0.245035757
2020	-6.580755715

Appendix 8 – Mining share of GDP (2010-2020)

Year	Mining share of GDP (%)
2010	16
2011	14.8
2012	12.5
2013	11
2014	10.9
2015	8.6
2016	8.1
2017	9.7
2018	9.5
2019	9.1
2020	12.5

Appendix 9 – Number of employees in mining sector (2010-2020)

Year	Number of employees in mining sector
2010	204,000.00
2011	221,000.00
2012	250,000.00
2013	263,000.00
2014	252,000.00
2015	241,000.00
2016	209,000.00
2017	205,000.00
2018	219,000.00
2019	236,000.00
2020	200,000.00

Appendix 10 – Net migration (2002-2017)

Year	Net migration
2002	42,330.00
2003	
2004	
2005	
2006	
2007	107,169.00
2008	
2009	
2010	
2011	
2012	163,730.00
2013	
2014	
2015	
2016	
2017	558,539.00

Appendix 11 – CO_2 emissions (2000-2018)

Year	CO_2 emissions (metric tons per capita)
2000	3.247220928
2001	3.085180102
2002	3.104355898
2003	3.148965633
2004	3.417427143
2005	3.443180386
2006	3.48833505
2007	3.916467803
2008	4.084807181
2009	3.87121211
2010	4.086146422
2011	4.437266212
2012	4.510826472
2013	4.720140459
2014	4.301488448
2015	4.561654853
2016	4.73170736
2017	4.712395783
2018	4.624872245

Appendix 12 – Research and development expenditure (2000-2018)

Year	Research and development expenditure
2007	0.30957
2008	0.37497
2009	0.35202
2010	0.32947
2011	0.35144
2012	0.3622
2013	0.3887
2014	0.37503
2015	0.38073
2016	0.36934
2017	0.35608