Wider impacts of climate action in Luxembourg

Final

Report to the Government of Luxembourg

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Author(s)	Kathryn Hampshire, Lucy Garland, Katrina Young
Reviewed by	Justin Goodwin
Signature	
Date	11/08/2021

Company Details:	Aether Ltd Oxford Centre for Innovation New Road Oxford OX1 1BY UK Registered in England 6630896
Contact:	enquiries@aether-uk.com +44(0)1865 261466 www.aether-uk.com

Executive Summary

Introduction

Actions to mitigate climate change, by reducing greenhouse gas emissions or absorbing carbon from the atmosphere, must work in synergy with the country's core social, environmental and economic growth and development strategies. These climate actions often have wider impacts beyond their mitigation focus that can be positive and negative and impact on a range of social, other environmental and economic objectives.

Considering the wider impacts can lead to increased engagement from strategic decision makers in government, and increased awareness and more informed decision making from the private sector and the public. This leads to more efficient analysis that identifies potential synergies and conflicts early on and supports more joined-up and climate conscious decision making.

This report aims to increase the understanding of the potential wider impacts of Luxembourg's actions to tackle climate change as well as barriers to implementing effective climate action with minimal negative wider impacts. This will support efficient policy making and the development of accelerated climate actions that work in harmony with wider government strategies and goals. The work links together Luxembourg's reported climate actions with the ten priorities set out in Luxembourg 2030: 3rd National Plan for Sustainable Development (NPSD) – see **Table 3** which shows the wider impacts and linkages between climate action and the NPSD.

Overview of Wider Impacts

Most climate actions have positive wider impacts. As expected, all climate policies have strongly positive links with NPSD priority 8 to protect the climate, adapt to climate change and ensure sustainable energy. There are also strongly positive links between climate actions and priority 3 to promote sustainable consumption and production, priority 7 to stop the degradation of the environment, priority 2 to ensure the conditions of a healthy population, and priority 4 to diversify and ensure an inclusive and forward-looking economy. For example, there can be increased economic activity through the growth of "green industries" such as building energy efficiency retrofits, improved human health through increased active travel, and ecosystem protection through agriculture and forestry management.

Policies that address energy consumption in residential buildings have the most positive potential wider impacts. This includes potential benefits to human health from improvements to living conditions and supporting poverty eradication through reduced fuel bills. Policies in the waste management sector also score highly for potential positive impacts through their contribution to sustainable consumption and the development of a low carbon, circular economy.

Some climate actions have the potential for negative wider impacts. Whilst most of the potential wider impacts from climate action are positive, there are areas of potential conflict where careful planning will be needed to avoid unintended negative consequences. This is particularly true when considering priority 5, plan and coordinate land use. For example, afforestation or renewable bioenergy crops can create competition for land use with food crops. Policies to increase active travel may include cycle lanes, which would necessitate reallocating space from other road users. However, Luxembourg has limited space and therefore this may cause a land use conflict.

Table 1: Wider impacts matrix of climate actions

Matrix key	Description
++	Strongly positive – this climate action could have significant benefits for the NPSD priorities
+	Positive – this climate action could have benefits for the NPSD priorities
0/+	Neutral or slightly positive – this climate action could have some benefits for the NPSD priorities
0	Neutral – this climate action will have little impact on the NPSD priorities
0/-	Neutral or slightly negative – this climate action could conflict with the NPSD priorities
-	Negative – this climate action could conflict with the NPSD priorities

		Transport			Renewable energy	Energy efficiency			Agriculture and LULUCF				Waste management		
		Shifting to public transport and active travel	Logistics	Shifting to electric vehicles	Replacing fossil fuels with renewable energy	Energy consumption: Residential buildings	Energy consumption: Public and commercial buildings	Energy consumption: Industry	Livestock management	Forest management	CAP greening	Other agricultural practices	Resource management	Prevention, Re-use, Preparing for re-use, Recycling, EfW, Landfill, Anaerobic Digestion	Use of Single Use Packaging, Polluter Pays Principle, Extended Producer Responsibility, Environment Protection Fund
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	+	0	0	0/+	+	0	0	0	0	0	0	0/+	0/+	0
	2. Ensure the conditions of a healthy population	++	+	+	+	++	++	+	+	+	0/+	+	0/+	+	+
	3. Promote sustainable consumption and production	+	+	+	+	++	++	++	0/+	+	+	+	++	++	++
	4. Diversify and ensure an inclusive and forward-looking economy	0/+	+	+	+	+	+	++	0	+	0	+	++	++	++
	5. Plan and coordinate land use	0/-	0/-	0/-	0/-	0	0	0	0	+	+	0	0/+	+	+
	6. Ensure sustainable mobility	++	++	++	+	0	0	0	0	0	0	0	0	0/+	0
	7. Stop the degradation of our environment and respect natural resource capacities	+	+	+	+	+	+	+	+	++	++	++	++	+	+
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++	++	++	++	++	++	++	++	++	++	++	++	++	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	+	0/+	0	+	++	0	0	0	0	0	0	0	0	0
	10. Ensuring sustainable finances	0	0/+	+	+	+	+	+	0/+	+	0	0	+	+	+

Overview of Potential Barriers

Despite clear potential wider benefits, some climate actions do not get implemented or are hindered by limited adoption uptake. Recognising and understanding the potential barriers to effective implementation of climate action in Luxembourg allows steps to be taken to minimise and overcome these barriers. The potential barriers to implementation identified during stakeholder consultation included:

- Challenges in translating national level targets to local level action due to a split in responsibility for decision making between the State and municipalities.
- Limited land resources with many competing users.
- A tendency to focus on short term policy gains instead of long-term benefits and a more reactive rather than proactive approach.
- Public perceptions and attitudes to climate policies.
- Low fuel and energy prices which hinder incentives to reduce/switch fuel use.
- Economic challenges in the agricultural sector restricting the uptake of climate measures.

By recognising the barriers, steps can be taken to minimise and overcome them. These are challenging barriers and there will need to be prioritisation of action and sustained cross-government collaboration to remove them. Many of the barriers can be mitigated through enhanced communication, awareness and consultation with the public, stakeholders and government departments.

Looking to the future

The Covid-19 pandemic has had far reaching and lasting effects on social, economic and environmental issues in Luxembourg. A green and fair recovery is one which jointly delivers carbon emissions reductions (and other environmental improvements) in ways which address social inequalities and public health outcomes whilst supporting the most vulnerable. The need for urgent action on climate has never been clearer, and this will require significant changes in lifestyles and behaviour of all of Luxembourg's citizens. The wider impacts of these actions need to be considered holistically to ensure conflicts are minimised and synergies are maximised, to leave the world in a better state than when we inherited it.

List of Acronyms

CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact
CO_2	Carbon dioxide
DALYs	Disability Adjusted Life Years
EfW	Energy from Waste
EMAS	Eco-Management and Audit Scheme
EPR	Extended Producer Responsibility
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
FEDIL	Fédération des Industriels Luxembourgeois
F-gas	Fluorinated gas
GDP	Gross Domestic Product
GHG	Greenhouse gas
IEA	International Energy Agency
LENOZ	Lëtzebuerger Nohaltegkeets-Zertifizéierung
LULUCF	Land Use, Land Use Change and Forestry
MDDI-DEV	Ministère du Développement durable et des Infrastructures – Département de l'Environnement
Mt	Megatonnes
NECP	National Energy and Climate Plan
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
NPSD	National Plan for Sustainable Development
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate matter
QALYs	Quality-Adjusted Life Years
R&D	Research and Development
SDGs	Sustainable Development Goals
STATEC	Institut national de la statistique et des études économiques
tCO_2eq	Tonnes of carbon dioxide equivalent
UK	United Kingdom
VAT	Value-Added Tax
WAM	With Additional Measures
WEM	With Existing Measures
WHO	World Health Organisation
ZWLS	Zero Waste Luxembourg Strategy

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1 Introduction

Actions to mitigate climate change and reduce air pollution often have wider impacts (see definition in section 1.2) beyond their mitigation focus. These impacts can be both positive and negative and influence a range of social, other environmental and economic outcomes such as increased economic activity, improved human health and job creation or negatives, such as competition for land between food and biofuel crops. All of these wider impacts need to be considered by policy makers driving forward greenhouse gas and air pollutant mitigation. In addition, some economic, social, or environmental actions may improve air quality and/or reduced greenhouse gas emissions as a co-benefit to the main purpose of those actions. For example, energy security needs may drive energy efficiency measures, but these measures also benefit the mitigation of greenhouse gases and air pollutants. It is therefore important to analyse wider impacts to identify potential synergies and conflicts, leading to more joined up and effective policy making.

This report brings together findings gathered during activities to investigate the wider impacts of climate action in Luxembourg. These activities included a literature review, a series of sector specific stakeholder engagement activities, and collation and analysis of the findings. More information on the methodology can be found in **Appendix 1**.

1.1 Report Aims and Objectives

This report aims to increase the understanding of the potential wider impacts of Luxembourg's actions to tackle climate change. This will support efficient policy making and the development of accelerated climate actions that work in harmony with wider government strategies and goals.

The objective of this report is to provide qualitative and where possible quantitative evidence of the wider impacts of Luxembourg's climate action aligned with the 10 priorities set out in Luxembourg 2030: 3rd National Plan for Sustainable Development (NPSD).

This objective is underpinned by the following research questions:

1. What are the wider qualitative and quantitative impacts of Luxembourg's climate actions?
2. What is the direction and possible magnitude for these wider impacts?
3. What are the most significant gaps in research and evidence relating to the wider impacts?
4. What perceived negative impacts are barriers to the uptake of Luxembourg's climate action?

Sections 1, 2 and 3 of this report provide background to the project including more information on the concept of wider impacts, an overview of key Luxembourg national strategies and a summary of Luxembourg's climate risks. Analysis of the wider impacts of climate action in Luxembourg is found in **section 4** and information on the potential barriers to the effective implementation of climate action in Luxembourg in **section 5**.

1.2 Definition of Wider Impacts

Climate actions are put in place to mitigate the effects of, or adapt to, the impacts of climate change. These actions can cover a range of activities such as energy efficiency

measures in homes, the use of renewable energy instead of fossil fuels (including in alternatively fuelled vehicles) and improved livestock management. There is a wide and increasing recognition that these climate actions can have additional, wider impacts socially, economically and environmentally (Committee on Climate Change, 2017). It is also clear that some actions being driven by other strategies (e.g. energy efficiency, sustainable farming) have clear climate benefits. For example, improved insulation as a measure to reduce energy consumption in businesses or homes will aid the achievement of greenhouse gas reduction targets. It may be primarily driven by energy security and/or climate related strategies and will have a range of "wider impacts" including:

- Reduced fuel bills - supporting economic, energy security and fuel poverty objectives,
- Reduced reliance on imported fuels – supporting economic and energy security objectives,
- Improved air quality – supporting strategies to improve public health through reduced air pollution.

The consideration of wider impacts can therefore lead to increased engagement from other ministries and stakeholders for a more joined up and climate impact conscious national decision-making process. Being able to present this analysis from the climate action centric or another perspective (e.g. to understand what climate actions are good and potentially bad for public health) improves understanding and engagement. This can highlight potential synergies and conflicts that may change prioritisation of actions. Analysis could reveal which policies could realise a range of benefits and bring engagement and support from a wider pool of stakeholders and which should be viewed more cautiously with conflicts to address.

2 Luxembourg's key national strategy areas

2.1 Climate actions

Actions relating to greenhouse gas emissions in Luxembourg are reported annually as required by the Governance of the Energy Union and Climate Action Regulation (EU 2018/1999), also known as the Governance Regulation. The Governance Regulation updates the existing Climate Monitoring Mechanism and brings it in line with Paris Agreement transparency requirements. It also allows for tracking progress towards the 2030 climate and energy legislation where under EU commitments, each EU Member State should develop a National Energy and Climate Plan (NECP), contributing to achieve a uniform EU climate action framework as well as to ensure that Member States collectively contribute to the EU's 2030 energy and climate targets.

Climate actions are outlined in Luxembourg's National Energy and Climate Plan 2021-2030 (NECP). The NECP is a planning and monitoring instrument related to the implementation of the EU's 2030 renewable energy and energy efficiency targets. The aim of the NECP is to accelerate the energy transition by improving energy efficiency, increasing the share of renewable energy and promoting more sustainable mobility options for individuals.

Luxembourg unilaterally commits to reduce greenhouse gas emissions from sectors outside of the Emissions Trading Scheme by 55% by 2030, compared to 2005 levels. Luxembourg also plans to increase the share of renewables from 11% in 2020 to 25% by 2030 whilst also reducing final energy demand by 40-44% by 2030, compared to the European baseline scenario.

A table of Luxembourg's current climate actions can be found in **section 4**.

2.2 Luxembourg 2030: 3rd National Plan for Sustainable Development

This report analyses the potential wider impacts of Luxembourg's climate action on its other key national strategy areas. This is performed by linking Luxembourg's reported climate actions with the 10 priorities set out in Luxembourg 2030: 3rd National Plan for Sustainable Development (NPSD)[1].

The National Plan for Sustainable Development specifies areas of action, objectives and measures to be taken in Luxembourg relating to sustainable development. This plan encompasses the Sustainable Development Goals (SDGs) (**Box 1**). In Luxembourg, there are five basic principles for sustainable development:

- Maintaining a high quality of life and a high level of human development for population residing and working in Luxembourg
- Respect for the ecological, social, and cultural rights of future generations and other nations of the planet (timeless and international responsibilities)
- Respect for ecological limits and the regenerative capacity of nature during use of natural resources at our disposal
- Defence of social cohesion through equality and solidarity

[1] https://environnement.public.lu/dam-assets/documents/developpement-durable/PNDD.pdf

- Preservation of economic prosperity through development of a buoyant economy

Box 1 – Sustainable Development Goals

The UN Sustainable Development Goals (SDGs) aim to achieve a better and more sustainable future for everyone. They address global challenges such as poverty, gender equality, climate change and the natural environment. There are 17 SDGs that are interconnected with a target date to achieve them by 2030. The goals are:

1: No poverty
2: Zero hunger
3: Good health and well-being
4: Quality education
5: Gender equality
6: Clean water and sanitation
7: Affordable and clean energy
8: Decent work and economic growth
9: Industry, innovation and infrastructure
10: Reduced inequalities
11: Sustainable cities and communities
12: Responsible consumption and production
13: Climate action
14: Life below water
15: Life on land
16: Peace, justice and strong institutions
17: Partnership for the goals

A mapping exercise on the implementation of Agenda 2030 led Luxembourg to define 10 priority fields of action in relation to sustainable development, while addressing the targets under the 17 Sustainable Development Goals which are relevant for the country:

1: Ensure social inclusion and education for all

The Government aims to strengthen Luxembourg's cohesion by minimising social exclusion and discrimination, reducing poverty and promoting social and professional inclusion. The Government aims to raise employment rates, reduce school dropout rates, promote lifelong learning and address gender imbalances in employment and political leadership[2]. One specific goal is to address the lack of moderately priced housing.

2: Ensure the conditions of a healthy population

Luxembourg Government aims to increase action against diseases and causes of early death (e.g. cancer, drugs, cardiovascular disease and road accidents) through the national health plan. Prevention is a priority objective. Another key ambition is to ensure access to good quality

[2]Programme National de Réforme 2021
https://meco.gouvernement.lu/en/publications.gouv_odc%2Ben%2Bpublications%2Brapport-etude-analyse%2Bprogramme-national-de-reforme%2B2021-pnr-luxembourg.html

health care for everyone through a social security system and to improve the provision of certain essential care services.

3: Promote sustainable consumption and production

To improve Luxembourg's ecological footprint, the Government wants to integrate the circular economy into everyday lives and the economy. This includes the transformation of waste into raw materials and the reduction of food waste. Water pollution and the protection of aquatic ecosystems will be addressed through the reduction of plastic. This action aims to increase Luxembourg's food self-sufficiency and increase sustainable consumption through awareness raising.

4: Diversify and ensure an inclusive and forward-looking economy

Luxembourg aims to promote more qualitative and inclusive growth that requires a smart, high value-added economy that consumes fewer resources and provides quality jobs for all. The Government wants to establish a clear legal framework that allows the country to reach its full economic potential whilst also avoiding environmental degradation and lowering of social standards. They want to strengthen relationships between business and research to foster innovation and employment.

5: Plan and coordinate land use

Land use planning policy that spans all actors, including the state, municipalities, citizens and developers will be pursued. Ministries and institutions will work together to increase the efficiency of the housing market and strengthen the economic and demographic role of regional centres. Access to urban areas will be ensured through infrastructure development and transformation of rural areas will be supported through establishment of basic services.

6: Ensure sustainable mobility

Luxembourg aims to reduce transport related greenhouse gas emissions through the promotion of public transport, electromobility and active mobility, notably through several premium schemes on public transport, electric vehicles, as well as changes to fuel taxes.

7: Stop the degradation of our environment and respect natural resource capacities

The Government aims to increase the share of organic farming to protect biodiversity and maintain ecosystem services. This action will work alongside the National Plan for the Protection of Nature to restore degraded habitats. The plan includes the creation of and improvement of natural habitats. The Government also wants to protect groundwater, re-establish waterways and maintain forests.

8: Protect the climate, adapt to climate change and ensure sustainable energy

Luxembourg would like to be more ambitious in their greenhouse gas reductions to 2030. One key area to target will be energy supply, including the reduction in energy consumption and transition to a greater share of renewable energy sources. The climate law, signed by the Government in December 2020, fixes Luxembourg's climate policy objectives to accelerate the implementation of the Paris Agreement. It enshrines both the unilateral commitment to reduce greenhouse gas emissions from sectors outside of the Emissions Trading Scheme by 55% by 2030, compared to 2005 levels and the targeting of a long-term goal of net zero emissions by 2050 at the latest. The law also explicitly excludes the use of nuclear energy for reaching those targets.

9: Contribute, on a global level, to poverty eradication and policy coherence for sustainable development

This strategy mirrors the vision of the Agenda 2030 to "leave no one behind". Luxembourg's cooperation policy targets the most vulnerable countries and focuses on multi-actor partnerships. The Government aims to ensure the cohesion of its policies, from a sustainable development perspective, in Luxembourg and in the rest of the world.

10: Ensuring sustainable finances

The Government aims to strengthen its position relating to green bonds and climate finance. It will continue to contribute to global climate financing efforts. Nationally, the Government aims to align traditional tools such as policy investment funds, public funds and intergenerational sovereign wealth funds with sustainable development priorities.

2.3 Other National Strategies

Whilst this report predominantly focuses on the links between climate actions and the priority actions outlined in the National Plan for Sustainable Development, it is important to consider other national strategies that may be impacted, positively or negatively, by climate actions. In addition to the ten priorities, this report also considers synergies and conflicts between Luxembourg's climate action and the National Air Quality Programme, the National Air Pollution Control Programme (NAPCP), the Integrated Energy and Climate Plan of Luxembourg 2021-2030 (NECP), the Third Industrial Revolution, the National Waste Management Plan and the Circular Economy Strategy. The other national strategies considered in the analysis are outlined below.

2.3.1 National Air Quality Programme and Air Pollution Control Programme

Air quality is regularly monitored by the Environment Agency through fixed measuring stations. Results of air quality monitoring showed levels of nitrogen dioxide (NO_2) concentration in exceedance of the limit value in the centre of the City of Luxembourg in the early 2000s and as such an air quality plan was developed and adopted in 2010. This plan was subsequently extended in 2017 to cover the entire territory of Grand Duchy of Luxembourg as well as other pollutants. Since then, only NO_2 showed concentration exceedances at 7 critical locations on the territory, all located along major highways. As a result, a new air quality plan aimed at reducing NO_2 emissions in order to remain below the average annual limit concentration value set by law has been adopted in June 2021.

Other air pollutants emissions such as $PM_{2.5}$, SO_2, NH_3, NOx and NM-VOC are now covered by Luxembourg's National Air Pollution Control Programme (NAPCP) under the "NEC Directive" (EU) 2016/2284 that was submitted to the European Commission in February 2021.

2.3.2 The Third Industrial Revolution

The Third Industrial Revolution (TIR) is a historical concept describing the technological and social transformations that took place from the second half of the 20th century. The Third Industrial Revolution is a process characterized by the transition to a new economic model defined by the coupling of information technologies, renewable energies and intelligent transport networks. For Luxembourg, the Third Industrial Revolution study aims to create a digitally connected smart economy, revitalising industry, bringing new economic opportunities, and creating a low-carbon economy. The implementation of the Third Industrial Revolution will enable economic growth through technological advances, increased efficiency and productivity, and more intelligent management of resources.

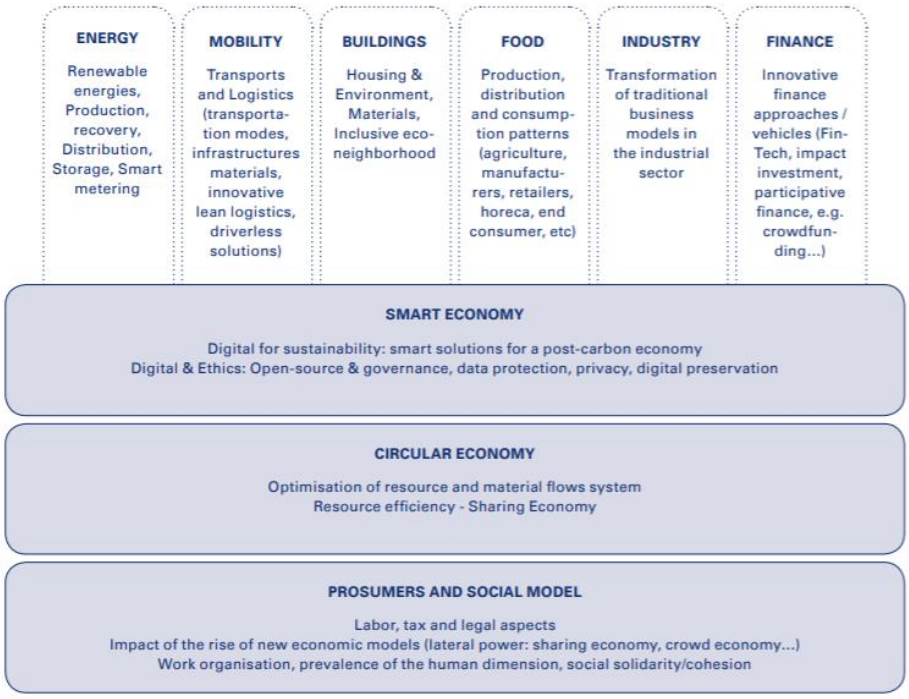


Figure 1 – Working groups for the Third Industrial Revolution in Luxembourg

2.3.3 National Waste Management Plan

The National Waste Management Plan is the operational tool for implementing the Waste Framework Directive (2008/98/CE) and defines the key waste management policies in Luxembourg. It specifies objectives for waste management and measures to enable these objectives to be achieved. The objective of this iteration of the national waste management plan is to promote the transition to the circular economy and to consider waste as a resource. It was therefore renamed as the National Waste and Resource Management Plan and is aligned with activities being carried out under the Third Industrial Revolution. This plan is also integrated under goal 12 of the Luxembourg 2030 Agenda "Establish Sustainable consumption and production patterns".

2.3.4 Circular Economy Strategy

Luxembourg's Circular Economy strategy was presented by the Government in February 2021 and has three major elements:

1. Identification of methods and tools for action by the State and municipalities to stimulate innovation including regulation and standards, financial aspects, and knowledge management. The last includes education, training, and public research as well as digitalisation and support from information communication technologies on data management.
2. Proposal of a methodology that enables action in key economic sectors through projects led by public actors and co-created with key stakeholders.
3. Provision of a mechanism for continuous consultation between ministries tasked with carrying out the strategy, stakeholders responsible for communication tools, and the implementing project holders.

3 Luxembourg's climate change risks

3.1 Climate change vulnerabilities and pressures

3.1.1 Climate

Over the last decade, Luxembourg has experienced an increase in average air temperature, with most temperature maxima occurring in the last 25 years. The increase in temperature seems most apparent in the winter periods, with longer frost-free periods and higher mean minimum air temperatures, as shown in **table 1**.

Table 2 - Temperature patterns in Luxembourg 1961-2020 (MeteoLux, 2021)

	1961-1990	1981-2010	2005	2010	2015	2020
Mean air temperature (°C)	8.3	9.3	9.6	8.7	10.4	11.3
Mean minimum air temperature (°C)	4.7	5.6	5.9	5.1	6.6	7.2
Mean maximum air temperature (°C)	12.3	13.1	13.6	12.4	14.3	15.5

The FNR-CLIMPACT research project showed that mean air temperature in Luxembourg could rise to 11.6°C between 2071 and 2100. Whilst annual total precipitation is expected is remain relatively stable up to 2100, there could be significant changes in seasonal variation with summer precipitation declining and winter precipitation rising. Winter precipitation is more likely to be rain than snow with the increasing temperatures and therefore this poses additional flooding risks (MDDI-DEV, 2018).

3.1.2 Population

Luxembourg currently has a high annual growth rate in population in comparison to neighbouring regions and this is predicted to continue to 2100. This is relevant to climate risk as increasing populations could increase the number of people exposed to the potentially harmful impacts of future climate change. For example, the elderly are more vulnerable to climate change impacts, and the proportion of the population that is elderly is projected to increase due to a fall in mortality in the over 60s (**Figure 2**).

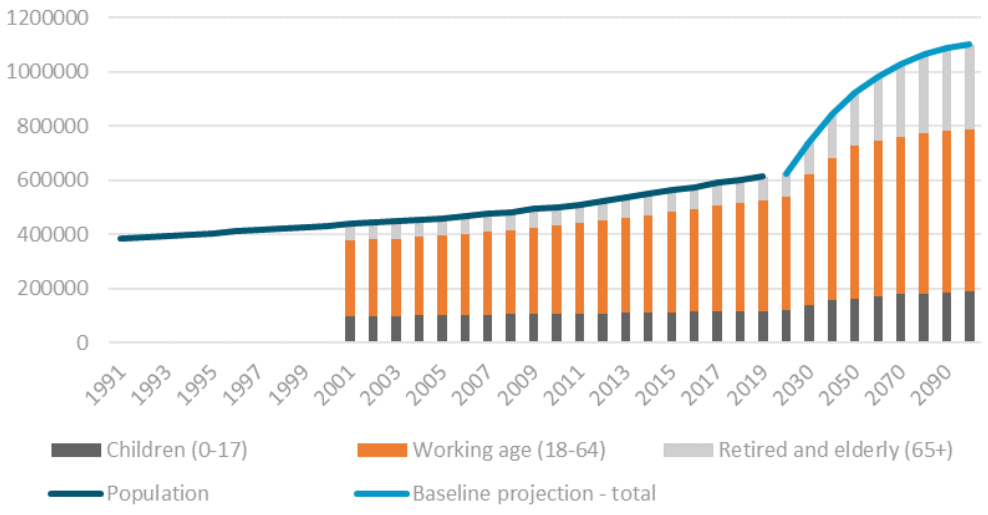


Figure 2 - Historical and projected population estimates for Luxembourg (MDDI-DEV, 2018)

3.1.3 Expected impacts of climate change in Luxembourg

The 7th National Communication of Luxembourg highlights key concerns for Luxembourg regarding climate change, including increased risk of forest fires, increases in heat extremes, decreases in summer precipitation and declining water quality. It also highlights several key potential impacts from climate change in Luxembourg:

Changes to natural cycles – Due to changes in air temperature, vegetation periods are expected to shift, being initiated earlier in spring and lasting longer into autumn. In the early vegetation stages, there could be an increased risk of frost damage. There could also be impacts on plant flowering, wildlife breeding cycles and migratory behaviours.

Increase heat exposure – This will be most severe in urban areas with high building densities. Higher air temperatures, especially at night, could increase the likelihood of extreme heat events with adverse human health consequences. The increasing frequency and intensity of heat waves is considered to be one of the greatest health threats from climate change.

Stress on agricultural plants and forest – Increasing temperatures could lead to more frequent and severe stress conditions for agricultural plants and trees, leading to a sharp degradation of Luxembourg's forests. Increased risks of disease outbreaks and infestations in forests due to milder winters and warmer average air temperatures could exacerbate the forest decline. For crops, more frequent extreme weather events could lead to higher yield variability and more irregular harvests.

Increased chance of winter flooding and drought – More seasonal precipitation patterns could present greater flood risks in winter whilst an increasing number and duration of dry periods in the summer could increase the risk of drought. Both have risks for human health and aquatic ecosystems.

3.2 Luxembourg's greenhouse gas mitigation priorities

Using estimates of greenhouse gas emissions and population from 2018, Luxembourg emitted 17.2 tCO_2eq per person. Among neighbouring countries, this is the highest per capita emissions in 2018 (**Figure 3**).

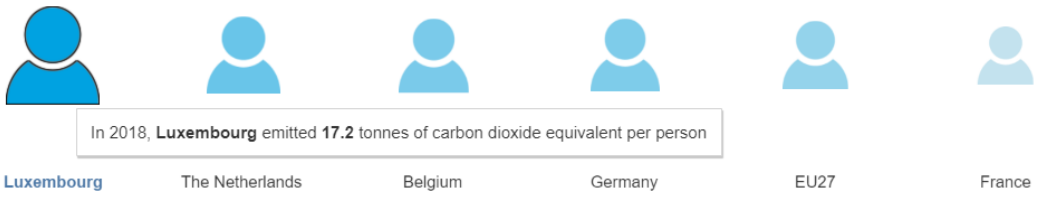


Figure 3 - Per capita emissions in 2018 for Luxembourg and selected neighbouring countries

In 2018, a total of 10 332 $ktCO_2eq$ was emitted in Luxembourg. 88% of this is attributed to the energy sector. This includes the transport sector which alone produces 58% of emissions. The Industrial Processes and Product Use and Agriculture sectors contributed 6% and 7% respectively to total emissions whilst the Waste sector contributed 1%. The Land Use, Land Use Change and Forestry (LULUCF) sector was a net sink in 2018 meaning that more carbon dioxide was removed from the atmosphere than the amount of greenhouse gases that were released (**Figure 4**).

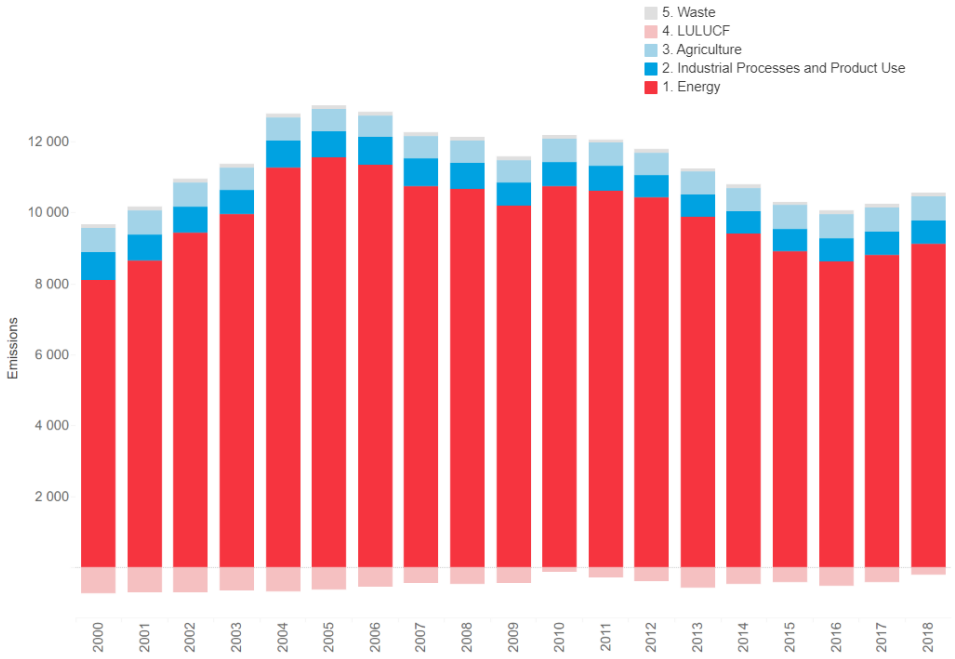


Figure 4 - Emissions (kt CO_2eq) by sector 1990-2018

Figure 5 illustrates how emissions are estimated to change in the future. The estimates are shown for the With Existing Measures (WEM) scenario and the With Additional Measures (WAM) scenario. For example, the graph shows that, with existing measures, energy sector emissions will remain largely the same up until 2040, however with additional measures, energy emissions could drop by 65% between 2018 and 2040.

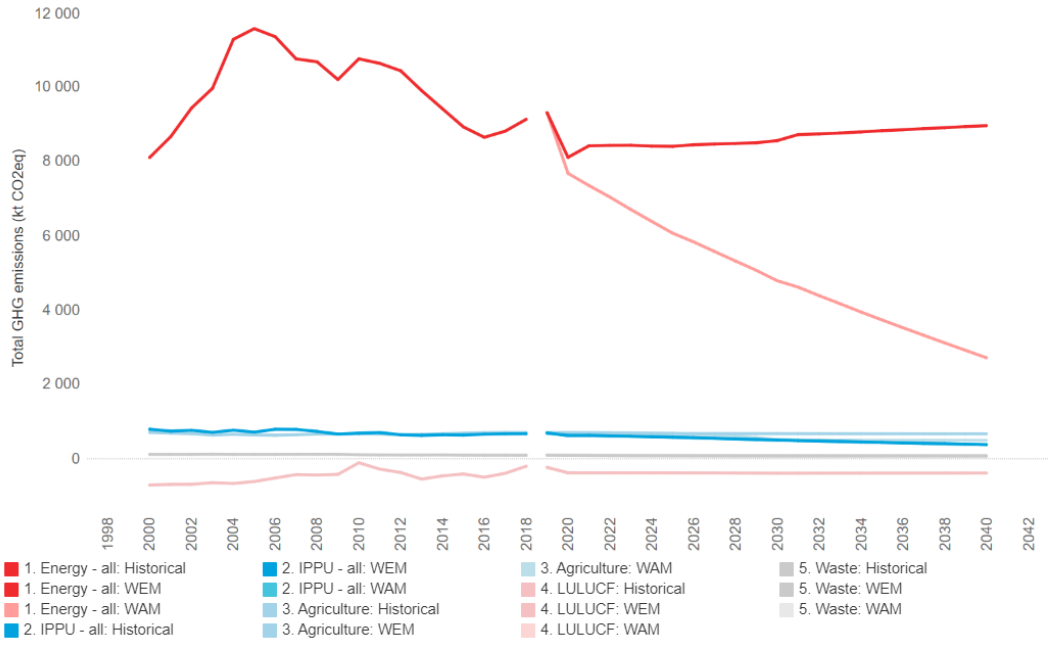


Figure 5 - Projected emissions (kt CO_2eq) by scenario 1990-2040

4 Wider Impacts of Climate Actions

For the purposes of this project, Luxembourg's climate actions have been grouped into five themes. Within each theme, climate actions have been aggregated into groups. **Table 2** shows how individual climate actions are aggregated to groups and sectors for this project. It should be noted that behaviour change is a cross cutting issue that should be considered for policies in all sectors. The action 'Environment and Climate Partnership and Sustainability Commission' has not been considered individually for this report but is instead linked to behaviour change. It is therefore considered to be a cross-cutting policy. The analysis contained in the following section, for example the scoring in the matrix (**table 3**), has been carried out considering current policies only and therefore does not include planned and future interventions.

The industry F-Gas Emissions Regulation has not been considered as part of this project because there is little evidence currently available in the literature on the wider impacts of F-gas regulations. More research is needed to identify the potential wider impacts, such as the impact of F-gas regulations on human health, and the magnitude of the potential impacts.

Table 3: Aggregation of individual climate actions into groups and themes

Theme	Group	Individual actions
Cross-cutting		• Climate Law • Carbon pricing • Climate Pact • Circular Economy Strategy • Land planning (sustainable & circular new settlements) • "Clean tech" cluster R&D activities
Transport	Shifting to public transport and active travel	• Enterprises mobility plans and "mobility budget" • Awareness raising campaigns (national and regional) • A traffic telematics system for public transport • MoDu 2.0 – Sustainable Mobility – reducing conflict between transport planning, mobility as a service, multimodal approach • Promotion of car-pooling • Excise duties on transport fuels • Free public transportation and expansion/optimisation of public transportation network • Active mobility
	Logistics	• Promotion of the "Lean+Green" Strategy • Revision of the taxation of ships sailing under the Luxembourg flag (registration fee) along the lines of the "Green Shipping" concept. • Reduction of truck traffic through the promotion of rail transport • Increase of landing fees
	Shifting to electric vehicles	• Tax incentives • Vehicle tax reform for company and private cars based on CO_2 • Improving and increasing framework and infrastructure (focus on EV infrastructure) • Increasing the number of hybrid and electric vehicles (purchase scheme for new EV & FCEV and, for a shorter term, for PHEV) • Increasing the use of mainly second-generation biofuels
Renewable energy	Replacing fossil fuels with use of renewable energy	• Biogas supply and feed-in tariffs • Actions to promote wind and solar energy and heat pumps, which should take the priority over biomass when possible • Renewables feed-in tariffs

Theme	Group	Individual actions
Energy Efficiency (using less energy)	Energy efficiency measures in **residential** buildings	• National renovation strategy • PRIMe House grant regime for energy efficient and sustainable buildings • Climate Bank – reduce rate-loans – or zero rate loans for low income families – for renovation projects, replacement technologies and energy consultations • Increasing energy efficiency – insulation and ventilation – reduced VAT rate for new and for renovation of existing buildings • Improve data collection on energy consumption • My Energy awareness raising • Guaranteeing sufficient human and financial means to My Energy • Education and training of workers – schemes and certificates • Increased energy efficiency standards for heating and hot water: introduction of a "nearly zero energy standard" • Streamlining the LENOZ certification to improve sustainability within the housing sector
	Energy efficiency measures in **public and commercial** buildings	• National renovation strategy • Sustainable and low-energy public building strategy for new and existing constructions • Increased energy efficiency standards for heating and hot water and lighting: introduction of a "nearly zero energy standard" • Monitoring of energy consumption in public buildings (smart meters and EMAS scheme) • Sustainability criteria for public procurement and planning process • My Energy awareness raising • Improve data collection on energy consumption
	Energy efficiency measures in **industry**	• FEDIL Voluntary Agreement • EU ETS regulation • Workforce training • Improve energy efficiency with new tools such as a "de-risking" instrument and transparency platforms for audits • Improve data collection on energy consumption
Agriculture and LULUCF (improving sequestration, reducing soil	Improved livestock management	• Climate smart agriculture investments • Research and knowledge transfer for climate-smart agriculture • Practices to reduce GHG emissions and ammonia • Methane reduction strategy

Theme	Group	Individual actions
disturbance and reducing GHG emissions from livestock)	Improved forest management	• Increase amount of dead wood in forests • Afforestation measures to increase carbon sinks • Forest management plans for public forests • Protection of existing forests • Increase size of forest nature reserves • Wood Cluster • Private forest nature reserve subsidy
	CAP green architecture[3]	• Crop diversification • Permanent grassland • Ecological focus area
	Improvements to other agricultural practices	• Conservation or zero tillage • Organic farming • Promotion of environmentally friendly technology for manure spreading • Further development of advisory services which advocate climate friendly plant and animal production

Waste	Improved waste management practices	• Zero Waste Luxembourg Strategy (ZWLS)
		  ○ Reaching zero littering
		  ○ Actions against food waste
		  ○ Prevention and recycling of packaging waste
		  ○ Improve the separated collection rate of bio-waste
		• Increase the lifespan of products and promote re-use increased preparing for re-use and recycling rates – “SuperDrecksKescht”
		• Prohibit open air incineration of waste
		• Use of woody biomass waste for energetic uses
		• Selective renaturation of buildings
		• Reduced emissions from energy incineration – energy recovery
		• Reduced landfilling of municipal waste (keeping landfilling in general as the least preferred waste management option)
		• Landfill methane recovery systems
		• Biological pre-treatment of municipal solid waste
		• Anaerobic digestion at biogas facilities

[3] In the future, CAP “greening” will be replaced by “eco-schemes”.

Theme	Group	Individual actions
		• Development of National Waste Management Plan • Advanced waste collection system
	Resource management	• Promotion of circular economy along the value chain (ZWLS) • Make recycling centres resources centres (ZWLS) • Sustainable construction using materials, incl. recycled/deconstruction materials, that could be recovered when a building has arrived to its end (ZWLS) • Create a market for “deconstruction” materials (ZWLS) • Reduce excavated soil/earth for new constructions (ZWLS)
	Other waste management policies	• Reduced use of single use packaging • Polluter Pays Principle • Extended Producer Responsibility • Environmental Protection Fund • Thermal recovery of sludge

4.1 Overview of wider impacts

The matrix below (**Table 3**) gives an overview of the findings in terms of the direction and magnitude of possible wider impacts associated with Luxembourg's climate actions. The wider impacts are assessed in relation to the ten priorities set out in Luxembourg's National Sustainable Development Plan. The 10 priorities, outlined in section 2.2, are listed on the left-hand side whilst the climate action groups, outlined in table 2, are listed across the top. The climate action groups are discussed in detail in the sub-chapters below.

The matrix highlights where "big-wins" could be made; policies that have multiple benefits for other national strategies, and where policies could potentially conflict with other national strategies. The categorisation of wider impacts is shown on a scale from strongly positive (++), through neutral or no additional impact (0) to negative wider impacts (-). Each category was also assigned a numerical score in order to provide a summary score for each row and column.

These initial weightings were decided based on evidence from the literature and expert judgement. During the consultation process with in-country sector experts, these initial weightings were discussed in the Luxembourg context and were adjusted accordingly.

Matrix key	Description	Score
++	Strongly positive – this climate action could have significant benefits for the NPSD priorities	+3
+	Positive – this climate action could have benefits for the NPSD priorities	+2
0/+	Neutral or slightly positive – this climate action could have some benefits for the NPSD priorities	+1
0	Neutral – this climate action will have little impact on the NPSD priorities	0
0/-	Neutral or slightly negative – this climate action could conflict with the NPSD priorities	-1
-	Negative – this climate action could conflict with the NPSD priorities	-2

Table 4: Wider impacts matrix of climate actions

		Transport			Renewable energy	Energy efficiency			Agriculture and LULUCF				Waste management			
		Shifting to public transport and active travel	Logistics	Shifting to electric vehicles	Replacing fossil fuels with renewable energy	Energy consumption: Residential buildings	Energy consumption: Public and commercial buildings	Energy consumption: Industry	Livestock management	Forest management	CAP greening	Other agricultural practices	Resource management	Prevention, Re-use, Preparing for re-use, Recycling, EfW, Landfill, Anaerobic Digestion	Use of Single Use Packaging, Polluter Pays Principle, Extended Producer Responsibility, Environment Protection Fund	Score
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	+	0	0	0/+	+	0	0	0	0	0	0	0/+	0/+	0	7
	2. Ensure the conditions of a healthy population	++	+	+	+	++	++	+	+	+	0/+	+	0/+	+	+	29
	3. Promote sustainable consumption and production	+	+	+	+	++	++	++	0/+	+	+	+	++	++	++	33
	4. Diversify and ensure an inclusive and forward-looking economy	0/+	+	+	+	+	+	++	0	+	0	+	++	++	++	27
	5. Plan and coordinate land use	0/-	0/-	0/-	0/-	0	0	0	0	+	+	0	0/+	+	+	5
	6. Ensure sustainable mobility	++	++	++	+	0	0	0	0	0	0	0	0	0/+	0	12
	7. Stop the degradation of our environment and respect natural resource capacities	+	+	+	+	+	+	+	+	++	++	++	++	+	+	32
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++	++	++	++	++	++	++	++	++	++	++	++	++	++	42
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	+	0/+	0	+	++	0	0	0	0	0	0	0	0	0	8
	10. Ensuring sustainable finances	0	0/+	+	+	+	+	+	0/+	+	0	0	+	+	+	20
	Score	17	15	15	17	20	15	15	9	16	11	12	17	19	17	

4.2 Transport

		Transport		
		Shifting to public transport and active travel	Logistics	Shifting to electric vehicles
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	+	0	0
	2. Ensure the conditions of a healthy population	++	+	+
	3. Promote sustainable consumption and production	+	+	+
	4. Diversify and ensure an inclusive and forward-looking economy	0/+	+	+
	5. Plan and coordinate land use	0/-	0/-	0/-
	6. Ensure sustainable mobility	++	++	++
	7. Stop the degradation of our environment and respect natural resource capacities	+	+	+
	8. Protect the climate, adapt to climate change, and ensure sustainable energy	++	++	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	+	0/+	0
	10. Ensuring sustainable finances	0	0/+	+

4.2.1 Summary of climate actions

In the transport sector, Luxembourg's climate policies and measures aim to decrease use of private vehicles, shifting towards forms of active mobility i.e. public transport and active travel (e.g. walking and cycling). Where private vehicle use is still necessary, Luxembourg is encouraging its citizens to switch to alternatively fuelled vehicles, predominantly electric vehicles. Through their climate actions, Luxembourg is therefore improving infrastructure for active mobility and electric vehicles whilst also encouraging these shifts through fiscal measures (e.g. excise duties on transport fuels and purchase premiums (for vehicles and private charging stations) for electric vehicles) and awareness raising campaigns.

Luxembourg is supporting a shift towards more sustainable logistics through its "Lean+Green Strategy", revision of taxes and landing fees, and promotion of rail transport as an alternative to road transport.

Although not an action listed under the climate actions, a shift towards increased home working could also have impacts in the transport sector. This cross-department action aims to increase the provision of co-working offices near Luxembourg's borders to reduce transport needs. This action is also particularly relevant in light of the COVID-19 pandemic where home working became the norm.

4.2.2 Potential wider impacts

Shifting to public transport and active travel

Increasing active travel and use of public transport while reducing the use of private vehicles has a wide range of potential benefits beyond the reduction in greenhouse gas emissions. These include the reduction of congestion, reduced noise pollution, improvements in public health and wider environmental benefits from the reduction of air pollutants (WHO, 2011, Shaw et al, 2014, C40 Cities and Ramboll, 2018). Air pollution, particularly from particulate matter (PM) and nitrogen oxides (NO_x), has been linked to a number of negative health impacts such as cardiovascular and respiratory disease (e.g. heart attacks, strokes, asthma), cancer, diabetes, and kidney and liver diseases (Jennings et al., 2019). The reduction of air quality pollutants from these policies will therefore positively impact the goals for a healthy population and reduced impact on the environment outlined in the NPSD. It will also positively contribute to the goals to reduce air pollution outlined in the National Air Quality Programme and the NAPCP. Sustainable transport policies fit into the Mobility working group of the Third Industrial Revolution.

Increased public transport facilities and infrastructure could also improve employment opportunities due to improved mobility (C40 Cities and Ramboll, 2018). This could be particularly true for lower income households as public transport offers more affordable transport options, connecting people to places of work. Reduced spending on transport, particularly fuel for private vehicles, could increase disposable income for households (C40 Cities and Ramboll, 2018). For low-income households, this could mean more money to spend on other essential items or increased comfort.

Active travel in particular substantially improves public health, beyond the health benefits of improved air quality, reducing the rate of many non-communicable diseases such as heart disease, diabetes and some cancers (Shaw et al., 2014, Workman et al., 2018). While increasing the uptake of public transport can reduce the prevalence of accidents, increases in walking and cycling can nevertheless increase them as walkers and cyclists account for 18% of road accident deaths on average in Luxembourg these last 10 years (STATEC, 2021). This does, however, vary with location and in developed countries the more people who walk and cycle the less risk of accidents to active travelers become.

The risk of accidents can also be reduced with high quality infrastructure, safety provisions, driver awareness raising and speed restrictions, so it is important to consider this when implementing active travel policies. A study in the UK estimated that an increase in physical activity, including increasing the amount of active travel, could save the National Health Service £17 billion within 20 years (approximately £255 per person using 2019 UK population) as a result of reductions in diabetes, heart disease and other health conditions. This number already accounts for the increased risk of road traffic accidents and shows the importance of active travel measures (Jennings et al., 2019).

There could also be local economic benefits to increased active travel. When people walk or cycle through their local area on a more frequent basis, they are more likely to shop in their local area. They are more likely to make lots of small trips, replacing journeys to large supermarkets. This can provide additional income to the local economy, supporting independent businesses and, in some cases, lead to regeneration of the local area (Sustrans, 2020).

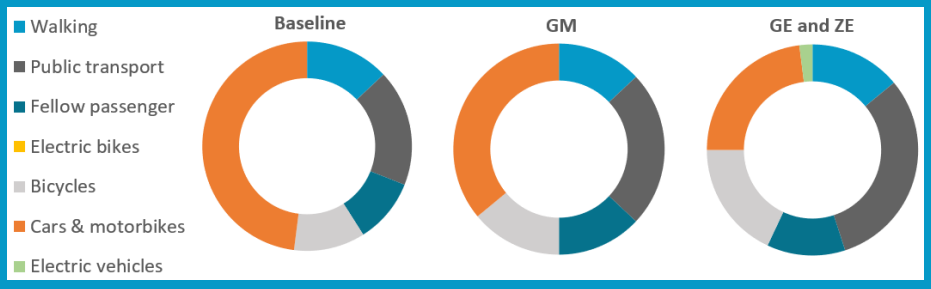
A challenge for Luxembourg is restricted space; adding walking or cycling lanes could therefore lead to land use conflicts. This could be particularly problematic if the conflict is between those engaging in active travel and road transport vehicles. This conflict will need to be considered when planning active travel interventions to ensure safety of all road users.

Case study: Co-benefits from mobility policies in Graz, Linz and Vienna, Austria (Wolkinger et al., 2018)

In this study, 3 scenarios were modelled:

- **Green Mobility (GM):** Locally set targets for modal share of trips in 2020/2025 are almost achieved. Policies include improvement of active travel infrastructure, improvement of public transport and parking regulations.
- **Green Exercise (GE):** Change in transport behaviour beyond policy targets through additional measures; promotion of active travel, expansion of car restrictions in city centre, expansion of public transport provision.
- **Zero Emissions (ZE):** Long-term scenario that assumes the same modal share as GE but with remaining driven kilometres done by electric vehicles (cars and public transport).

Modal share of trips by scenario:



Summary of impacts

Co-benefits		GM	GE	ZE
GHG emissions	tCO_2eq	-289 680	-534 260	-956 500
Mortality	Physical activity	-417	-891	-891
	Air quality	-135	-284	-647
Macroeconomic effects	GDP	-0.01%	-0.00%	-0.07%
	Welfare	+0.2%	+0.3%	+0.2%
	Employment	+0.1%	+0.1%	+0.1%

The table above shows very clear health benefits from policies to reduce transport emissions and encourage active mobility. There are also economic impacts, but these vary depending on the recipient. The greatest cost savings for households are seen under the ZE scenario, due to a decreased use of private vehicles and a shift to cheaper forms of transport – active travel and public transport. However, the reverse is true for public sector costs as the Government has to pay for infrastructure improvements and running of transport services.

The wider impacts of actions to increase the amount of teleworking and working from home are highly variable and often very dependent on individuals, their situation, and their personal preferences. Increased teleworking could lead to improved air quality and reduced fuel use through a reduction in commuting traffic, congestion, and office energy consumption (Bojovic et al., 2020, Hook et al., 2020). However, these reductions could not be as large as expected if individuals make more journeys for non-work purposes. For example, as the need to travel to work locations is reduced, workers could move further away. This however means that trips to the grocery store or to work on non-teleworking days are longer. Individuals could also make more trips to see friends and family as social interaction is more limited by home working (Moeckel, 2017, Hook et al., 2020). Energy costs for workers could also increase as they must cover the cost of increased home energy consumption.

Regarding the mental and physical health of employees working from home, there are also very mixed findings. Some evidence points to significant benefits; a more relaxed working environment, greater autonomy, greater flexibility, and financial savings on commuting costs. Other evidence, however, suggests more negative impacts including lower levels of social support, social isolation, work-family conflicts, and financial impacts from increased home energy bills (Oakman et al., 2020, Vyas & Butakhieo, 2021).

Logistics

The most significant additional benefit of the logistics policies outlined in Table 2 relates to the goal to ensure sustainable mobility. However, there could also be benefits for ensuring a healthy population, promoting sustainable consumption and production, and protecting the environment and climate. This group of policies feeds into several Third Industrial Revolution priority areas including Mobility and Food.

Encouraging the use of more efficient, low carbon vehicles, including cleaner trucks and rail, could have additional benefits through reduced air pollution and reduced congestion, reduced pollution in particular leading to benefits for the health of people and the environment (WHO, 2011, Shaw et al, 2014, Pisoni et al., 2019). Increasing the efficiency of logistics vehicles through the “Lean + Green” Strategy could also have economic benefits for the operators through reduced fuel bills.

Encouraging rail transport for logistics is one action being implemented by Luxembourg to promote sustainable logistics. However, this must be done with caution as the rail network is small and not always possible to expand. Logistics and passenger trains will therefore be competing for this resource and demand must be carefully balanced so as not to push either group towards less environmentally friendly transport options. This is one of the reasons behind Luxembourg’s investments for duplicating the existing railway network towards the South.

Shifting to electric vehicles

Luxembourg is encouraging its citizens to switch to alternative fuel vehicles, mainly electric vehicles, which could help to ensure sustainable mobility, a healthy population and protection of the environment and climate.

Increasing the use of alternative fuel vehicles can reduce air pollution and noise (Messagie et al, 2014, Jabben et al., 2012). Increasing the use of electric vehicles is expected to have

the greatest positive impact on air quality and noise. Modelling undertaken on Madrid and Barcelona shows that with 40% vehicle fleet electrification there was an 11% and 17% reduction in NO_X emissions respectively for each city (Soreta et al., 2014). Reducing NO_x emissions would have benefits for human and ecosystem health. However, the link between electric vehicles and human health benefits is not given the maximum positive score in this analysis due to the potential and unknown impacts of particulate matter (PM). It is possible that PM emissions could increase or remain constant with a shift to electric vehicles (Jennings et al., 2019) due to the vehicles being heavier and therefore emitting more PM from brakes and tyre wear, compared to internal combustion vehicles (Timmers & Achten, 2016). The true impacts are however currently unknown. This will therefore need to be observed and accounted for going forwards as the population and driven kilometres increase.

The air quality related benefits would depend on the current level of the vehicle EURO standard in the country. Replacement of older lower standard vehicles with electric ones will have a more significant impact on air quality than the replacement of newer higher EURO standard vehicles. The Luxembourg fleet is relatively modern and therefore the benefits may not be as significant. Increasing the prevalence of biofuels for transport may have some negative impacts due to land use conflicts between crops grown for food and crops grown for biofuels. However, Luxembourg plans to limit the use of biofuels, and in particular first-generation biofuels that will be limited to 5%.

The switch to alternative fuel vehicles will therefore positively impact the aim to reduce air pollution, especially NO_2 from transport, under the National Air Quality Programme. The air quality benefits will however depend on the fuel mix of electricity generation in the country in the case of electric vehicles (Buekers et al, 2014). In addition, there would be a decrease in engine noise of 3-4 dB if the entire fleet is replaced with electric vehicles (Soreta et al., 2014).

4.3 Renewable Energy

		Renewable energy
		Replacing fossil fuels with renewable energy
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	0/+
	2. Ensure the conditions of a healthy population	+
	3. Promote sustainable consumption and production	+
	4. Diversify and ensure an inclusive and forward-looking economy	+
	5. Plan and coordinate land use	0/-
	6. Ensure sustainable mobility	+
	7. Stop the degradation of our environment and respect natural resource capacities	+
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	+
	10. Ensuring sustainable finances	+

4.3.1 Summary of climate actions

When replacing fossil fuels, Luxembourg will prioritise electrification, followed by renewable energy and, as a last option, biomass. This is supported by actions to promote wind, solar and heat pumps as well as providing feed in tariffs for renewable energy and biogas. Solar PV in functional buildings is likely to be demanded as building energy demand targets are calculated assuming that a certain proportion of energy comes from solar PV. The targets for new residential buildings, written in law, are also calculated in a way that makes them impossible to achieve with fossil fuels.

4.3.2 Potential wider impacts

Replacing fossil fuels with use of renewable energy

Increasing the production and use of affordable national renewable energy can have a positive impact on energy security, and can increase the resilience of energy systems, insulating the economy from price volatility and supply disruptions of fossil fuels (Clarke et al., 2014). Increasing renewable energy production could also reduce air pollution which has associated health benefits (Schwanitz et al, 2015). For example, a study in the UK found that decarbonising power generation to achieve the national 80% emissions reduction target could result in a fall in $PM_{2.5}$ emissions of more than 40% by 2050 and this could save up to 1.1 million cumulative life years by 2154 compared to a scenario with no future action (Milner et al., 2020). Whilst the UK and Luxembourg are not comparable in size, this evidence suggests some health benefits could be achieved in Luxembourg.

However, the health benefits directly felt in Luxembourg could be minimal as most electricity is imported. It is relevant though when considering the global impact of activities occurring in Luxembourg. Certain renewable energy products have specific wider impacts. For example, the waste products from biogas production can benefit agriculture as the digestate can be used to improve soil quality and the wastewater from the acidic air scrubbers for ammonia removal can be used as a N-S fertiliser (Vaneeckhaute et al, 2013).

When identifying potential conflicts, it is important to consider the land use required and potential noise and sight impacts from wind and solar installations. These installations require space which is limited in Luxembourg. Equally, there may be some resistance from nearby residents of planned installations due to their aesthetics and noise. Increasing the use of biomass in Luxembourg could however negatively impact air quality, increasing emissions of particulate matter (PM) (Apsimon et. al., 2009). This would negatively impact the goals for a healthy population and continue the degradation of the environment as well as negatively impact the aim to reduce air pollution outlined in the National Air Quality Programme and Air Pollution Control Programme. However, the use of biomass will be limited in Luxembourg, with first generation biomass use limited to 5%.

4.4 Energy Efficiency

		Energy efficiency		
		Energy consumption: Residential buildings	Energy consumption: Public and commercial buildings	Energy consumption: Industry
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	+	0	0
	2. Ensure the conditions of a healthy population	++	++	+
	3. Promote sustainable consumption and production	++	++	++
	4. Diversify and ensure an inclusive and forward-looking economy	+	+	++
	5. Plan and coordinate land use	0	0	0
	6. Ensure sustainable mobility	0	0	0
	7. Stop the degradation of our environment and respect natural resource capacities	+	+	+
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++	++	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	++	0	0
	10. Ensuring sustainable finances	+	+	+

4.4.1 Summary of climate actions

Regulations in Luxembourg for both residential and functional (commercial and public) buildings are ambitious, with the target of these buildings being low energy/passive buildings. The National Renovation Strategy is applicable to residential and functional buildings as are actions to monitor energy consumption, to improve data collection and to raise awareness.

For residential buildings, the climate actions provide grants, loans, and other financial instruments for building improvements, such as insulation and ventilation. Energy efficiency standards for heating and hot water are more stringent than before whilst workforce training and certification aims to improve the overall sustainability of the housing sector.

For functional buildings (commercial and public buildings), energy efficiency standards are improved, and sustainability criteria are put in place for public procurement and planning processes alongside increased monitoring on energy consumption.

For industry, Luxembourg's climate actions encourage increased energy efficiency through both voluntary and legal agreements as well as through improving knowledge through workforce training, increased data collection and the provision of new tools to monitor energy efficiency.

4.4.2 Potential wider impacts

Energy Efficiency Measures in Residential Buildings

Increasing energy efficiency can lead to cost savings for households and an overall reduction in energy demand. A study in Ireland suggests that retrofit measures in the detached housing stock could achieve a 65% reduction in heating costs and associated CO_2 emissions for houses built before 1979 and 26% for more modern houses (Ahern, C., 2013). Energy efficiency measures can improve the indoor climate (e.g. through better temperature regulation, reduced draughts) which can reduce excess winter mortality and hospitalisations as well as reducing non-communicable diseases and improving mental health (IEA, 2014). However, for health benefits of improved energy efficiency to be maximised, measures must be accompanied by sufficient ventilation to minimise the risk of increasing exposure to indoor air pollution, such as radon and $PM_{2.5}$ from cooking, fires and smoking (Milner et al., 2020) For Luxembourg, a greater benefit from housing improvements could be additional comfort during the summer and reduced exposure to heat extremes. This is increasingly the case as average air temperatures and extreme heat events increase.

A study on the housing stock in the UK indicated that energy efficiency measures could reduce CO_2 emissions by 0.6 Mt annually and result in 850 fewer disability-adjusted life-years (DALYs) per million population per year (Wilkinson et al., 2009). A similar study in England found that improved energy efficiency of homes could lead to 2 200 quality adjusted life years (QALYs) gained for every 10 000 people over 50 years, providing ventilation regulations are met (Milner et al., 2020). Additionally, it is thought that renovating existing buildings within Europe to improve energy efficiency could:

- Produce a permanent annual benefit to society of €104-175 billion in 2020 depending on the level of investments made from 2012 to 2020
- Save €52-75 billion from lower energy bills
- Produce a benefit of at least €9-12 billion from the co-benefits of reduced outlay on energy subsidies and reduced air pollution from energy production (Copenhagen Economics, 2012).

If the health benefits from an improved indoor climate are included, the benefits are increased by an additional €42-88 billion per year (Copenhagen Economics, 2012). Other benefits of increasing energy efficiency of residential buildings include reduced fuel poverty (IEA, 2014), a short-term increase in jobs especially in the case of retrofitting and increased property value. Minor illnesses e.g. cold, flu and coughs, make up a significant number of lost working days, therefore improving living conditions with subsequent improved health of workers can have wider morale, productivity, and economic benefits (Jennings et al., 2019). Policies and wider impacts in this group are highly relevant for the Energy group under the Third Industrial Revolution.

A deep retrofit programme in Luxembourg could also create a substantial number of jobs. For example, a deep urban retrofit programme across the EU could result in an additional 1 million jobs between 2015 and 2030 (Day et al., 2018). The increased demand for skilled and professional workers in the field of energy efficiency retrofits could also drive training and education opportunities as more workers upskill (Day et al., 2018).

Energy Efficiency Measures in Public and Commercial Buildings

Increasing energy efficiency in public and commercial buildings reduces running costs. An overall increase in building efficiency can have economic benefits, saving businesses and organisations money which could increase profit or could be invested in staff, new technology, or further efficiency savings (Jennings et al., 2019). Reducing energy demand could reduce air pollution, which benefits health through reduced exposure to pollution (Lazar & Colburn, 2013). Additional health benefits, both mental and physical, come from improved working environments and the associated increased comfort (IEA, 2014). Increased energy efficiency of buildings can increase employee productivity, with economic benefits (Lazar & Colburn, 2013).

Energy Efficiency Measures in Industry

Increasing energy efficiency in industry can have numerous wider benefits. It can lead to reduced air and water pollution as well as reducing costs for businesses and a more sustainable use of natural resources (OECD, 2019). Reductions to air and water pollution will have a positive impact on the goal to stop the degradation of the environment and a healthy population, through the health benefits of reduced air pollution. The co-benefit of reduced air pollution will also contribute to the aims to reduce air pollutant concentrations set out in the National Air Quality Programme and Air Pollution Control Programme.

The industrial productivity and operational benefits of increased energy efficiency are usually between 40 and 50% but can be up to 2.5 times the value of the energy savings, depending on the type of investment (IEA, 2014). In addition, increasing energy efficiency in industry can have additional benefits to the overall economy: increasing the number of jobs and GDP (IEA, 2014) and contributing to a diverse, inclusive and forward-looking economy and sustainable finances.

4.5 Agriculture and Land Use, Land Use Change and Forestry (LULUCF)

		Agriculture and LULUCF			
		Livestock management	Forest management	CAP greening	Other agricultural Practices
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	0	0	0	0
	2. Ensure the conditions of a healthy population	+	+	0/+	+
	3. Promote sustainable consumption and production	0/+	+	+	+
	4. Diversify and ensure an inclusive and forward-looking economy	0	+	0	+
	5. Plan and coordinate land use	0	+	+	0
	6. Ensure sustainable mobility	0	0	0	0
	7. Stop the degradation of our environment and respect natural resource capacities	+	++	++	++
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++	++	++	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	0	0	0	0
	10. Ensuring sustainable finances	0/+	+	0	0

4.5.1 Summary of climate actions

Luxembourg aims to reduce greenhouse gas and ammonia emissions from livestock through improved livestock management practices and the ammonia reduction strategy. Included in the climate actions is the promotion of climate smart agriculture. Research into what will be included under this term for Luxembourg is, however, still ongoing. Currently, this includes subsidies to farmers to improve livestock practices but there will be more actions in the future.

The climate actions also aim to improve forest management through afforestation, forest management plans, protection of existing forests, and improvements to management techniques. These are expected to provide an overall increase in the size and quality of Luxembourg's forest areas.

Currently under the Common Agriculture Policy (CAP) green architecture, Luxembourg focuses action on crop diversification, creating permanent grasslands, and ecological focus areas. However, CAP greening will, in the future, be replaced by "eco-schemes" which could result in a change in climate actions.

Finally, there are some other climate actions relating to the agriculture and LULUCF sectors such as the promotion of organic farming and other farming techniques that could lead to greenhouse gas emissions reductions (e.g. conservation tillage).

4.5.2 Potential wider impacts

Livestock Management

Improvements to livestock waste management will further improve air quality by reducing ammonia emissions, positively impacting the goals for a healthy population and stopping the degradation of the environment but also contribute to the aim to reduce air pollution set out in the National Air Pollution Control Programme. Additionally, improving energy efficiency of animal housing will reduce running costs in the long-term and improve air quality (IEA, 2014). However, the energy efficiency measures are only applicable to pig and poultry production as cattle production takes place in modern, open-spaced cattle barns with no heating and mostly natural ventilation. Pig and poultry are a relatively small proportion of livestock activities in Luxembourg and therefore this wider impact is relatively minor in comparison.

The goals for a healthy population and minimising degradation of the environment will also benefit from the methane reduction strategy, which is not implemented yet but will aim to reduce methane emissions through improved manure management and livestock diet management. If this strategy was to be implemented with these measures, the link between livestock management action and goal 7 would be increased to the most positive rating.

Forest Management

In addition to GHG sinks, all of the forestry related measures could lead to an increase in or preservation of biodiversity. Policies aimed at increasing the amount of deadwood can lead to more available, richer habitats (Hodge & Peterken, 1998). Policies that increase the area of forests will improve flood protection, reducing surface water run off through increased surface roughness and infiltration capacity of soil, as well as water quality and quantity (Sing et al, 2017). These co-benefits will help to minimise degradation of the environment and to respect natural resource capacities. If forests are available to the public there can be additional physical and mental health benefits (Sing et al, 2017). Sustainable forest management can additionally improve income for farmers and landowners (Carpentier, Vosti, & Witcover, 2000) and could contribute to a diverse, inclusive and forward-looking economy, sustainable finances and sustainable production and consumption.

CAP green architecture

In the current CAP there are three main CAP greening policies are crop diversification, creating and protecting permanent grassland and creating and protecting ecological focus areas such as hedges. The latter two could have additional benefits of improving biodiversity (Underwood & Tucker, 2016) (Kizeková et al., 2018). Creating and protecting grasslands could have additional hydrological benefits at both the local and regional scale (Kizeková et al., 2018). In addition, there could be small benefits to human health relating to increased exposure to green landscapes. Crop diversification has the most potential, additional benefits: improving soil's drainage and water retention capacity and resistance to erosion as well as improved fertility.

CAPRI modelling undertaken by the EU Joint Research Centre showed that CAP Greening in Europe is expected to increase food prices slightly but also to increase income for farms on average by 0.9%. The total production of arable crops is however expected to decrease, driven by the reduction of arable land. Creating and protecting grassland dominates these

effects (Gocht et al., 2016). Overall the study concluded that while there were wider environmental benefits to CAP greening, as discussed above, they may be limited.

Other Agricultural Practices

In addition to the previously discussed agricultural measures Luxembourg has some measures to increase organic farming and to increase the implementation of conservation or zero tillage practices that would need to be enhanced in the future. Both measures would likely improve carbon stocks and therefore increase fertility and yields as discussed above (Krauss et al., 2020). This could have benefits for the economy and the achievement of sustainable finances as well as encouraging sustainable consumption and production.

Organic farming can improve soil drainage and water-holding capacity and resistance to erosion. Increasing organic farming can also improve biodiversity and lead to less reliance on non-renewable sources of materials, which could contribute to a circular economy (Muller, 2009). Reducing tillage, through conservation or zero tillage techniques, can also improve the drainage and water-holding capacity of soil as well as resistance to erosion from both wind and water. There is an additional benefit of reducing nitrogen run-off though reduced or zero tillage (Kurkalova, Kling, & Zhao, 2003).

4.6 Waste Management

		Waste management		
		Resource management	Prevention, Re-use, Preparing for re-use, Recycling, EfW, Landfill, Anaerobic Digestion	Use of Single Use Packaging, Polluter Pays Principle, Extended Producer Responsibility, Environment Protection Fund
3rd National Plan for Sustainable Development – 10 priorities	1. Ensure social inclusion and education for all	0/+	0/+	0
	2. Ensure the conditions of a healthy population	0/+	+	+
	3. Promote sustainable consumption and production	++	++	++
	4. Diversify and ensure an inclusive and forward-looking economy	++	++	++
	5. Plan and coordinate land use	0/+	+	+
	6. Ensure sustainable mobility	0	0/+	0
	7. Stop the degradation of our environment and respect natural resource capacities	++	+	+
	8. Protect the climate, adapt to climate change and ensure sustainable energy	++	++	++
	9. Contribute, on a global level, to poverty eradication and policy coherence for sustainable development	0	0	0
	10. Ensuring sustainable finances	+	+	+

4.6.1 Summary of climate action

The Zero Waste Luxembourg Strategy is a key strategy for climate actions in the waste sector, including actions to reduce food waste, reduce packaging waste, and to increase rates of recycling. Working in collaboration, the waste sector climate actions aim to reduce the amount of waste generated and to move up the waste hierarchy (**figure 6**).

Figure 6 - Waste hierarchy

The actions also promote the use of anaerobic digestion.

A key concept in the waste sector is the circular economy, eliminating waste and pollution through design, keeping resources and materials in use, and regenerating natural systems. This is encouraged through Luxembourg's circular economy strategy and through the Zero Waste Luxembourg Strategy.

4.6.2 Potential wider impacts

Resource management

Reducing material use and selection of materials based on their longevity and suitability for re-use and recycling to reduce greenhouse gas emissions has strong positive impacts relating to sustainable consumption and production and creating a more forward-looking economy. In particular, these policies help to develop Luxembourg's circular economy, leading to more sustainable consumption of natural resources (New Climate Economy, 2018). Policies in this area could have benefits for the population through job creation and environmental improvements from reduced resource use. However these benefits are less certain than for other waste management practices detailed below.

Waste Management Practices – Prevention, Re-use, Preparing for re-use, Recycling, EfW, Landfill, Anaerobic Digestion

Policies and measures that reduce the amount of waste have wider benefits such as less environmental impact and savings in resources and energy. Diversion from landfill and the expected increase in recycling can also increase resource efficiency and reduce energy consumption. These wider impacts will contribute to a diverse, inclusive and forward-looking economy, sustainable finances and sustainable production and consumption. These policies are also highly relevant to the cross-cutting theme of Circular Economy in the Third Industrial Revolution as they boost resource efficiency and promote the reuse of materials. Moving to a more circular economy, particularly in industrial sectors, could decouple economic growth and material use, leading to more sustainable consumption of natural resources (New Climate Economy, 2018).

Anaerobic digestion of biowaste to produce biogas has additional benefits. By-products can be used for soil conditioning which can lead to increased carbon stocks. Waste management through anaerobic digestion can lead to reduced odour and increased sustainability through replacing fossil fuels as an energy source (Antizar-Ladislao & Turrion-Gomez, 2010). The replacement of fossil fuels will contribute to the sustainable development goals of ensuring sustainable energy and a sustainable economy. The use of naturally occurring woody biomass for energetic uses will also have positive impacts on the share of renewable resources. If agricultural waste biogas would be used for transport fuel, this could also have benefits for promoting a lower-carbon mobility.

Increasing prevention, re-use, preparing for re-use and recycling increase resource efficiency and reduce energy consumption from extracting activities in quarries and from the processing of raw materials (e.g. scrap metals used in the steel industry rather than iron ores) and help to work towards a circular economy. The selective renaturation of buildings will also economize resources and energy. Increasing prevention, re-use, preparing for re-use and recycling can also increase the number of jobs and also job quality compared to jobs in other waste treatment activities (landfilling, incineration). Re-use of waste is a priority under the Zero Waste Luxembourg Strategy and therefore there will be job creation related to a need for more recycling and re-use centres. For example,

if EU plastic sorting and recycling capacity increases fourfold on 2015 capacity by 2030, this could create 200 000 new jobs across Europe (European Commission, 2018). In addition to the prevention and recycling of packaging waste, the promotion of multiple use packaging as well as the aim of reaching zero littering can boost resource efficiency and reduce both human and wildlife exposure to toxic chemicals (New Climate Economy, 2018), with associated health benefits for people and the environment. Food waste prevention can also have impacts such as household cost savings, a shrinking agri-food sector, a mild negative macroeconomic impact and reductions in environmental pressures (greenhouse gas emissions, land use and water abstraction).

Policies that increase methane recovery systems for landfill gas will have the additional benefits of increasing revenue for landfills and reducing the cost of energy. Landfill gas recovery systems can also create jobs through the need for specialised technology and expertise and improve local air quality (World Energy Council, 2016).

Waste Management – Use of Single Use Packaging, Polluter Pays Principle, Extended Producer Responsibility, Environment Protection Fund

Reducing the number of single use packaging consumed will considerably reduce the amount of waste disposed in Luxembourg reducing both human and wildlife exposure to toxic chemicals from plastic (New Climate Economy, 2018), with associated health benefits. The polluter pays principle is likely to lead to less waste being produced and more waste being collected separately for high quality recycling. Extended Producer Responsibility (EPR) holds producers responsible after the product's service life. It gives producers a greater motivation to design products that minimize environmental and health impacts.

The environmental protection fund aims to provide funds relating to water protection and sanitation, prevention and control of air pollution, noise and climate change, prevention waste prevention and management, protection of nature and natural resources and remediation and rehabilitation of waste disposal sites and contaminated sites. This will contribute to the goals to stop the degradation of the environment and protect the climate.

5 Potential Barriers to Implementation

Despite the clear multiple benefits, some climate change actions do not get implemented or are hindered by limited adoption uptake. Similarly, two areas could implement the same policies but with different results (C40 Cities and Ramboll, 2018). Understanding the barriers to implementation in the Luxembourg context was a key theme during the stakeholder consultation. By recognising the barriers, steps can be taken to minimise and overcome them. **Table 4** below outlines some of the barriers identified during the consultation phase that could arise in implementing climate policies in Luxembourg and possible ways to overcome them. These are elaborated further in the text below. Further information on individual barriers and how to remove them can be found in the Long-term Renovation Strategy and in the NECP.

Table 5: Potential barriers to implementing climate policies

Potential barrier	Description	Possible solutions
Translating national targets to local levels	In Luxembourg there is a split of responsibility for decision making between the State and municipalities. This makes it challenging for the State to impose a national level action as municipalities have the freedom to implement policies in their own way.	• Luxembourg Climate Pact with municipalities – already in place • Municipal level goals and targets • Encourage collaboration between municipalities • Regular communication and collaboration between State and municipalities • Highlighting benefits (direct and indirect) of national action to local communities
Limited resources and land use restrictions	As a small country, Luxembourg has limited space with many competing users and limited resources to address problems.	• Put in place a framework for good governance • Put in place good processes for land and infrastructure planning • Encourage cross department decision making
Short term nature of political decisions and tendency to be reactive	As with many other countries, in Luxembourg there tends to be too much focus on short term economic gain, instead of considering long-term investments. There is also a tendency to look at neighbouring countries and wait to see which actions work best. This creates a delay in action. The delay could also result from it taking too long to implement actions, meaning that technology and systems are out of date by the time they are implemented.	• Consider long-term impacts when making policy decisions • Consider short term wider impacts in addition to economic impacts • Try to take early action, accepting that it won't always be successful but it will provide valuable learning • Invest time in research of emerging technologies and early adopters
Ineffective analysis of barriers prior to implementation	In Luxembourg there is sometimes insufficient analysis of potential barriers prior to policy implementation therefore leading to decisions that are not based on the best available data and do not remove the right barriers.	• More resources allocated to the planning phase • Wider consultation before implementation • Cross department decision making
Public perceptions	Deeply held values influence a person's perception of risk and which information they value. These values often inform decisions on new situations (Moser & Ekstrom, 2010).	• Regular stakeholder and public consultation • Further social science research into the influence of values • Further research on the drivers of individual interactions with climate change policy

Low energy and fuel prices	Low costs of energy and fuel in Luxembourg do not incentivise people to change. However, simply increase the price of fossil fuels may have socio-economic impacts that need addressing, such as increased fuel poverty. Fuel tourism is also an issue to Luxembourg due to the lower fuel prices.	• Carbon tax on fuels • Subsidies on renewable energy for low income households
Legal and logistical challenges	Some policies implemented at the EU level can present challenges, for example marketing standards and food labelling requirements. Similarly, some packaging materials are not currently adapted for recycling and those that are adapted are more expensive.	• Diversify the electricity mix to include renewables to reduce use of energy from waste • Consider whole value chains and life cycle analysis of products • Encourage consumers to also consider life cycle impacts • Research innovative packaging solutions • Consider using food labels to raise awareness
Economic challenges in the agriculture sector	There is a careful balancing act between climate action in the agriculture sector and maintaining economically sustainable farms. High economic pressure on farmers can restrict the extent to which they can implement climate friendly measures. Consumers are also often unwilling to pay more for added environmental credentials of a product.	• Encourage farmers to be early adopters of new technologies • Ensure imported goods have the same high environmental standards as European products • Carry out awareness raising activities with the public to encourage them to value climate credentials of a product

Translating national targets to local levels

In Luxembourg there is a split of responsibility for decisions between the State and municipalities. This makes it challenging for the State to implement national level actions and plans in a consistent and cohesive manner. Municipalities have a lot of autonomy, therefore making it difficult to impose national actions, even by law. For example, if the State wanted to implement an action to remove parking spaces and introduce a cycle lane, even if the road were a State-owned road, the municipality would make the final decision as the road comes under the municipality jurisdiction.

This can therefore make the implementation of climate action highly political as it is dependent on decisions made by the municipality mayors. Mayors can change on a relatively frequent basis and can easily undo the work of the previous mayor. The State therefore relies on shared visions and good collaboration with the municipality mayors.

Potential solutions to this challenge lie in communication and collaboration between municipalities and between the State and municipalities. Luxembourg is already engaged in these activities through the Luxembourg Climate Pact, which engages municipalities on a climate and energy management system, with, in its 2.0 version, also actions on air quality and circular economy. The Pact offers rewards to municipalities implementing national level policies to solve local problems and acts as a way of engaging with citizens. But there will always be challenges, for example the cost to the State from financial rewards.

Taking advantage of the Climate Pact 2.0, another potential solution could be to develop municipality level goals and targets, particularly highlighting how these fit with the national plans for emissions reductions. This could encourage collaboration and a feeling

that everyone has their part to play in reducing emissions. There could also be increased engagement with citizens and local level politicians to highlight the wider impacts of national climate actions for local communities. For example, the health benefits for individuals of a switch to active travel.

Limited resources and land use restrictions

Luxembourg is a relatively small country which has limited resources and limited land area. Shortage of skilled labour and a lack of human resources are a significant barrier. Land area is restricted with many users competing for space. One example of this is with afforestation. Afforestation is a potential climate action but there is already pressure on land resources. Land is being used for urbanisation and farmers are struggling to find sufficient amount of land for agriculture, therefore they are unwilling to give up the land they do own for afforestation. Another example is the ever rapidly increasing land and housing prices that complicate further investments in existing building renovation when acquiring a property asset.

Due to the limited land resources, good governance is needed to reach Luxembourg's climate goals. The Climate Framework Law set an objective for the country to be carbon neutral by 2050. It also provides the framework for new platforms on governance with stakeholders.

Efficient and joined-up planning processes should be put in place to reduce the impact of limited resources. Land and infrastructure planning should consider all users. A cross-departmental approach to planning could be more effective, to pool expertise, gather a wide range of views and to ensure policies are joined-up and complimentary.

Short term nature of political decisions and tendency to be reactive

This challenge is linked to the previous one in that mayors and State politicians can change on a regular basis. This can mean that short term policy decisions are favoured over long-term strategies for political reasons. The economic system of Luxembourg is also based on short term profits and therefore there is an unwillingness to invest in long term action. For example, when implementing industrial energy efficiency measures, if the payback is more than six months, it is unlikely to get implemented unless there are significant productivity gains.

There is also a tendency in Luxembourg to look to neighbouring countries for potential climate actions. Whilst this may improve effectiveness of implementation as policies can be tweaked based on the experience of other countries, it also means that Luxembourg is often a step behind and not proactive. A challenge can also be the speed at which action is implemented. In the area of climate change, technology is changing rapidly. If implementation is slow, this can mean that once an action is implemented, the technology is already out of date. It can cause a reluctance to invest in new technology for fear of it changing in the near future.

To overcome these challenges, Luxembourg should look to be more proactive and take early action. There is a risk that actions won't work out but there can always be valuable lessons drawn from these cases. The State could invest time in researching emerging technologies and other early adopters to gain insight into possible future trends and promising options. Luxembourg could also consider building wider impacts and a consideration of long-term impacts into the policy decision making process. This will

allow a more holistic view of the proposed policy and can highlight the additional benefits.

Ineffective analysis of barriers prior to implementation

Sometimes, barriers to effective implementation of a policy are not sufficiently analysed prior to a policy being introduced. This can mean that, for example, the State spent a significant amount on providing incentives for bikes and public transport. There was an initial rise in tram use, including for very short trips that would have previously been made by foot however this policy did not have as big an impact as initially intended. This revealed that money was not the most important barrier to use of public transport, but rather the quality of the service, infrastructure, and ease of use. These barriers, particularly in infrastructure, are harder to address.

To overcome this challenge, Luxembourg could put more emphasis on the planning phase of the policy making process. We have previously highlighted the resources constraints existing in Luxembourg, however, more time spent in the planning phase could lead to an overall improvement in the whole policy cycle as policies would be designed to be more effective and remove the right barriers. This could involve wider consultation, cross departmental planning, and a more detailed analysis of possible barriers.

Public perception

Public perception and behaviour can be significant barriers to the implementation of climate action but the underlying drivers for this barrier can be complex. It could be simply a lack of awareness on a particular issue, or it could be related to a deeply engrained belief. Awareness raising and public education schemes can be expensive, but they are often not prioritised highly enough. Similarly, regulatory instruments can be unpopular as people like to have the freedom to choose what products they buy. Citizens and consumers are often faced with decisions to buy locally sourced products that are higher quality with greater environmental credentials and on price. Many people do not have the luxury to be able to spend more to support sustainability when cheaper, less sustainable options are available.

Overcoming this barrier can be particularly challenging but steps can be made through regular stakeholder and public consultation to identify views and preferences. This information can feed into more targeted awareness raising activities. More widely there needs to be more social science research into the influence of values on decision making and on the drivers of individuals' interactions with climate policy.

Low energy and fuel prices don't incentivise change

In Luxembourg, energy prices are currently low, which is good for consumers but doesn't incentivise change such as lowering energy use or switching to renewable energy. For example, low transport fuel prices in Luxembourg are driving fuel tourism i.e. fuel being bought in Luxembourg but used elsewhere. Increasing prices suddenly is not an option as this could cause socio-economic issues such as increased fuel poverty.

A carbon tax has now been introduced in Luxembourg, but it is currently at a low level increasing year on year, so it will need between five and ten years before it has a significant impact. However, this is one solution to overcoming the challenge of low energy prices. To minimise potential impacts on low-income households, Luxembourg

could implement subsidies on renewable energy for these households alongside the carbon tax.

Legal and logistical challenges

Some policies implemented at the EU level can present a challenge, such as marketing standards, food labelling norms, and best before dates. The latter can present a barrier to actions to reduce food waste, for example. These EU level policy instruments should benefit from a greater degree of flexibility but without compromising a country's ability to secure food resources. As part of the new Farm to Fork Strategy, the EU is revising some policy instruments to consider climate strategies, and this could help to overcome this barrier. At a national level, Luxembourg could consider using food labels to raise awareness among consumers on the environmental impacts or credentials or different products.

Packaging is also a significant logistical challenge as many composite materials are not adapted for recycling and consumers are not aware that packaging needs to be separated. There is a need for more investment is packaging that does not need to be separated, or that is compostable, however the price of these smarter packaging solutions is often a barrier. To start to overcome this barrier, there needs to be greater research into innovative technologies that offer packaging of comparable quality and price. There should also be shift in thinking about products to take account of the whole life cycle.

Reducing waste is a key policy area for Luxembourg however in doing so this would also reduce the amount of electricity that could be generated from the Energy from Waste (EfW) plant. To remove this barrier, Luxembourg should diversify its electricity source to include renewables to reduce reliance on EfW plant generated electricity and still meet energy demand. However, since energy generation from the EfW plant only represents around 2% of electricity supplied in Luxembourg, this is a lower priority consideration.

Economic challenges in the agriculture sector

Under the Common Agricultural Policy, farmers receive incentives for implementing more environmentally friendly practices, however these are not always correctly calculated. There is also an often- forgotten period of higher costs when a new technology is first introduced as the farmer is learning about the technology and how best to implement it. More generally, there is a constant balancing act between climate action and economically sustainable farms. There is high economic pressure on farmers which limits their ability to try new climate friendly measures, especially when consumers are not willing to pay for the additional environmental credentials of the product. There is additionally a constant pressure on local products from lower priced imports.

Luxembourg could consider encouraging farmers to be early adopters of new technologies through, for example, incentives, greater communication, or help with the technology roll out. Regarding products, Luxembourg could put measures in place that ensure that any imported products meet the same standards as European products and ensure that they are aligned with climate action targets. Taxes on products based on their climate credentials is an option but implementation would need careful planning as these measures are often unpopular with consumers. Public awareness raising

activities could also be used to make environmental standards more of a priority for consumers when choosing products.

6 Conclusions and recommendations

Luxembourg recognises that it needs to consider a broad range of complex social, environmental and economic dynamics when designing its climate mitigation actions. This report sets out the results of a cross ministry consultation on the potential wider impacts, positive and negative, of climate actions. The work has looked at climate action related to the priorities set out in "Luxembourg 2030: 3rd National Plan for Sustainable Development" and other key national strategies.

This analysis, of the potential synergies and conflicts between policies, allows for more joined up decision making and allows for more efficient use of strategic resources. It is clear that cross government collaboration and engagement in identifying co-benefits and potential conflicts can help to identify where investment can be focused to maximise benefits and where conflicts can be addressed early on before investments are made.

Many of Luxembourg's climate actions have positive wider impacts, with those addressing energy consumption in residential buildings having the most potential co-benefits. Some climate policies have the potential for negative wider impacts, such as land use conflicts between afforestation and agricultural land.

The report identifies potential barriers to effective implementation of climate action, outlined in section 5. The removal of these barriers would allow for more effective decision making and the maximising of the positive wider impacts of climate action. These barriers are challenging and there will need to be prioritisation of actions, sustained cross government collaboration, and enhanced communication and consultation with stakeholders and the public.

Further work should be undertaken to explore and, where possible, quantify the co-benefits arising from the measures undertaken and planned. This will provide more evidence to support business cases for action and engagement by other stakeholders such as those in public health. Economic benefits, such as healthcare savings due to increased active travel with health and social benefits, can be a strong case for policy development. Not all climate policies were analysed in this report; more research is needed to identify potential wider impacts of industrial and solvent emissions and policies, such as the impact of F-gas regulations on human health, and the magnitude of the potential impacts.

The analysis in this report only considered existing policies, not planned or future measures. We recommend that wider impacts analysis is performed when developing new policies for implementation, to ensure they are designed in a manner that reduces conflicts and maximises synergies.

The Covid-19 pandemic has had far reaching and lasting effects on social, economic and environmental issues in Luxembourg. A green and fair recovery is needed which delivers carbon emissions reductions in ways which also address social inequalities and public health outcomes whilst supporting the most vulnerable. A holistic approach to climate and Covid-recovery measure design is needed to ensure short-term responses do not conflict with long-term priorities.

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Appendix 1

Methodology

To complete the study, the following activities were undertaken:

- Review of Luxembourg's climate actions
- Extraction of relevant literature from the Aether co-benefits and wider impacts database
- Literature review to identify further literature and sources that are specific to the Luxembourg context
- Workshop with a range of stakeholders

The evidence collected from the literature review and workshop was analysed and the key relationships between climate actions and wider impacts were mapped out. The key findings were synthesised with cross-cutting themes, key conclusions and recommendations being drawn out.

Literature Review

The literature review aimed to identify both academic and grey literature sources that contained information on wider impacts of climate action relevant to the Luxembourg context. Aether used sources such as Google Scholar, journal databases (e.g. Science Direct and Research Gate), institute websites and the Luxembourg Government website to gather this information. Searches were conducted using key words. These key words considered variation in terms used for wider impacts including 'co-benefits', 'ancillary benefits', 'conflicts' and 'trade-offs'. It also searched beyond 'wider impacts' as some evidence talked about the specific impacts such as 'air quality' or 'fuel poverty'. Additional relevant literature and datasets were also identified at the stakeholder workshop.

Workshop

Sector expert engagement was carried out with Luxembourg Government stakeholders over a series of online workshops. Prior to the workshop, a summary report was circulated to participants outlining an introduction to the project and the initial findings. The following five 1.5 hour long workshops were carried out:

- Introduction to the project and initial findings
- Transport
- Energy
- Agriculture and LULUCF
- Waste and circular economy

During each of the sector specific workshops, we gave a presentation of the initial findings. We then had two interactive discussion sessions, the first around the initial findings and how we should change the initial matrix scores to reflect the Luxembourg context, and the second on the possible barriers to implementation of effective climate action in the given sectors.

Following the workshop, attendees were given a further week to provide any remaining comments. We then collated the comments, along with the summary report to produce the main report, this document.

Oxford Centre for Innovation

New Road

Oxford

OX1 1BY UK

+44(0)1865 261466

www.aether-uk.com