Observatoire
de la Politique
Climatique

Annual Report 2022

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PREFACE: The Heat is On!

"The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. *(very high confidence)*[1]" [2]

With the accumulation of extreme events in recent years, the scale and interconnectedness of impacts of climate change on individuals, organisations, and nations, can no longer be ignored, not even in Luxembourg, which usually finds itself sheltered from the storm.

In October 2021, the *Government in Council* nominated the members of the '***Climate Policy Observatory***' (OPC; Observatoire de la politique climatique) which was set up in the framework of the Luxembourgish climate law[3]. The OPC is a scientific council currently composed of seven members with expertise in various fields of climate-related sciences. This document presents the first Annual Report of the OPC. It sets the scene by providing background information, establishes the OPC's main principles and provides a first (cross-) sectoral assessment of Luxembourgish climate policies.

The Luxembourgish climate law sets clear targets of reducing greenhouse gas emissions by 55% by 2030 (compared to levels of 2005), and to become climate neutral (net zero emissions) by 2050 at the latest. One of the executing regulations of the law specifies the breakdown of the emissions targets set for each sector between now and 2030[4]. The measures to reach these targets for each sector are laid out in the first integrated National Energy and Climate Plan (Plan national intégré en matière d'énergie et de climat, PNEC)[5]. Each country needs to submit a progress report on the NECP every two years. The next 'Integrated national energy and climate progress report' is due in March 2023. The Ministries are also currently working on the draft update of the latest notified NECP that goes up to 2030 and needs to be submitted by June 2023. The OPC's report and recommendations will provide valuable input for this draft update. The final update of the latest notified integrated NECP is due in June 2024.

How can the OPC contribute in navigating the fight against climate change and its impacts in Luxembourg and beyond?

The OPC members recognise the emissions targets as one main overarching goal for mitigation measures that warrants extremely fast emissions reductions across all of Luxembourg's sectors and activities. The prerequisite for collaborative action by all actors of society, the economy and government to achieve these climate mitigation goals is the understanding that the relevant policies and measures will allow safeguarding of our rural and urban ecosystems so they can continue to satisfy human needs in a changing climate and provide the foundations most needed for humanity's survival. Here, we refer to the whole of the different natural and anthropo-ecosystems as a 'life support system'.

The OPC aims to provide input on the relevance and impact of specific policy actions, as well as highlighting gaps and contradictions within and across different sectoral sets of policies. This should be done within the context of nature protection and water protection. The OPC takes a cross-sectoral systemic perspective to highlight particularly salient interactions and ways in which different systems may constrain each other that are more easily missed with a more sectoral lens. The OPC will also comment, where appropriate, on which aspects of policies might help or hinder transformative processes and those that might foster or present barriers for change.

In this first Annual Report, the OPC develops its main principles that will give direction to our analyses and recommendations. These principles include the reduction of fossil fuel dependence through behavioural and technological changes, the need for just transition as well as ideas for a new and transformative governance. The application of these principles in practice will become more apparent in the individual chapters of this report and over the course of our collaborative work over the next four years.

This report is based on previous research conducted by the members of the OPC and lively discussions. Over a number of daily meetings, OPC members developed a shared understanding of the climate policy context in Luxembourg as well as a mutual comprehension of each member's work in order to find a common language. Further, with areas of future challenges identified, the report offers starting points for further and more in-depth investigations.

Luxembourg, October 2022

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Observatoire de la politique climatique - OPC

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The OPC

The Government of the Grand Duchy of Luxembourg – more precisely the *Government in Council* – nominated the members of the '*Climate Policy Observatory*' (OPC; Observatoire de la politique climatique) in October 2021, which was set up in accordance with Article 7 of Luxembourg's national climate law[6]. The Observatory may issue opinions on its own initiative.

> The OPC's mission encompasses advising on projects, actions or measures that may have an impact on climate policy; scientifically evaluating the measures carried out or envisaged in the field of climate policy and to analyse their effectiveness, as well as to propose new measures; to write an annual report for the Government on the implementation of the climate policy; and to propose research and studies in relevant fields.

The OPC is a scientific council currently composed of seven members chosen from individuals with expertise in a field directly related to the Observatory's mandate. Further selection criteria included the complementarity of expertise across relevant fields of knowledge, and gender diversity. Fields of expertise of the actual members range from climate modelling, climate economics and climate finance, economic geography and political science, multi-criteria analysis and life-cycle assessment, biochemistry, and system science. Four members are based in Luxembourg and three members are based abroad. For more details on the experts see Annex I. The members are appointed to serve for 5 years in addition to their main employment elsewhere and dispose of an annual budget from the State budget[7].

A *Secretariat* supports the OPC's mission with two additional experts highly skilled in greenhouse gas (GHG) projections, climate policies and environmental regulation. The Ministry of the Environment hosts the Secretariat. The *Bureau of the OPC* consists of the President, the Vice-president and the Secretariat.

Mission statement – the OPC members' understanding of their role

The OPC strives to meaningfully contribute to inform policy and practice relating to climate change in a science-based and impactful manner. Identifying leverage points for effecting changes that are as wide-ranging and rapid as possible is a shared priority by all its members, given the urgency of the situation. Based on the open legal remit and diversity of expertise and experience of its members, the OPC believes it holds several unique strengths that will allow it to provide added value in areas that are particularly difficult to address from the position of just one Ministry or organisation. The OPC is particularly well placed to respond to the assessment of the Intergovernmental Panel on Climate Change (IPCC) stating that "climate governance is most effective when it interacts across multiple policy domains, helps establish synergies and minimise trade-offs", as well as connecting different actors across sectors and governance levels (national, municipal, level of individual actors). Moreover, the IPCC points out that effective governance will rely on the empowerment of diverse actors to engage in making profound changes to prevailing ways of thinking and doing.

Executive Summary: Transforming Luxembourg into a sustainable and decarbonised society

Luxembourg's climate law fixes a clear target to set the country on a path to become climate neutral by 2050 at the latest. The 'Climate Policy Observatory' (OPC; Observatoire de la politique climatique) is tasked with monitoring annual progress. This is the first climate report for Luxembourg.

A set of policy measures have helped reduce emissions in Luxembourg over the past years. However, in order to reach its ambitious climate targets, Luxembourg needs to implement further far-reaching measures and systemic changes throughout the whole of society in the upcoming years. The overarching goal is a rapid and just transformation towards a sustainable and decarbonised society.

Against the backdrop of this primary objective, the reports identifies three core principles through which it assesses Luxembourg's efforts in the fight against climate change.

Luxembourg's economy needs to strongly **reduce its current dependence on fossil fuels**. The complete decarbonisation of the economy requires deep structural changes. Traditionally, climate policies incentivise **technological changes** such as energy efficiency improvements and renewable energy production. While these changes are necessary and need to be strengthened in the future, they are not sufficient. In addition, **behavioural changes** and societal changes are needed to allow the adoption of low-energy and sufficient lifestyles.

The transformation of Luxembourg's economy and society towards climate resilient development needs to be rapid, but also based on the principles of "**just transition**" to be accepted by all. Important guiding questions, when designing and implementing these policies are: What are the costs, benefits and risks associated with a policy? How are costs, benefits and risks shared amongst people and other stakeholders?

The implementation of these deep structural changes requires **new and transformative governance**: this means transforming not only the mix of policy instruments, but also the governance processes and structures. We highlight three key elements for the development of legitimate transformative governance efforts across all stages of the policy cycle: integrated, participative, and fair governance.

Luxembourg is a small but very open economy. The current accounting system for greenhouse gases (GHG) misses part of emissions of goods consumed in Luxembourg. This is why the OPC recommends **accounting for consumption-based emissions**, following the Swedish example. **Consumption-based emissions** allow the counting of emissions embedded in imported goods and thus incentivises global decarbonisation.

The rapid and just transformation to a sustainable and decarbonised society requires action **across all sectors of society**. The report provides an initial, non-exhaustive list of recommendations on how to proceed in selected sectors. These sectors are among the key greenhouse gas emitters in Luxembourg. The report suggests a decarbonisation approach that can be broken down into three main levers:

- **Sufficiency**: popularise low-energy sufficient lifestyles
- **Energy efficiency**: increase the energy efficiency of the Luxembourg economy
- **Renewable energy production**: decarbonise energy production and imports

Sector-specific recommendations include:

Buildings

- Reduce ambient temperature in homes and offices
- Reduce floor area per person
- Promote resilient buildings
- Require landlords to invest in renovations of leased homes or apartments
- Ban fossil heating systems

Transport

- Land use and urban planning to reduce space for cars
- Develop plans for a 15-minute city
- Promote working from home
- Incentivise the modal shift from a car-centric to a shared, soft mobility system
- Increase share of electric vehicles (EV) and ban fossil fuel vehicles

Energy Systems

- Increase the capacity of renewable energy production and thereby decrease the dependency on imports from foreign markets
- Continue and strengthen the measures in place aiming for a reduction of final energy demand
- Stop direct/indirect subsidies to fossil energy
- Increase the share of renewable power production

Food, Agriculture and Forestry

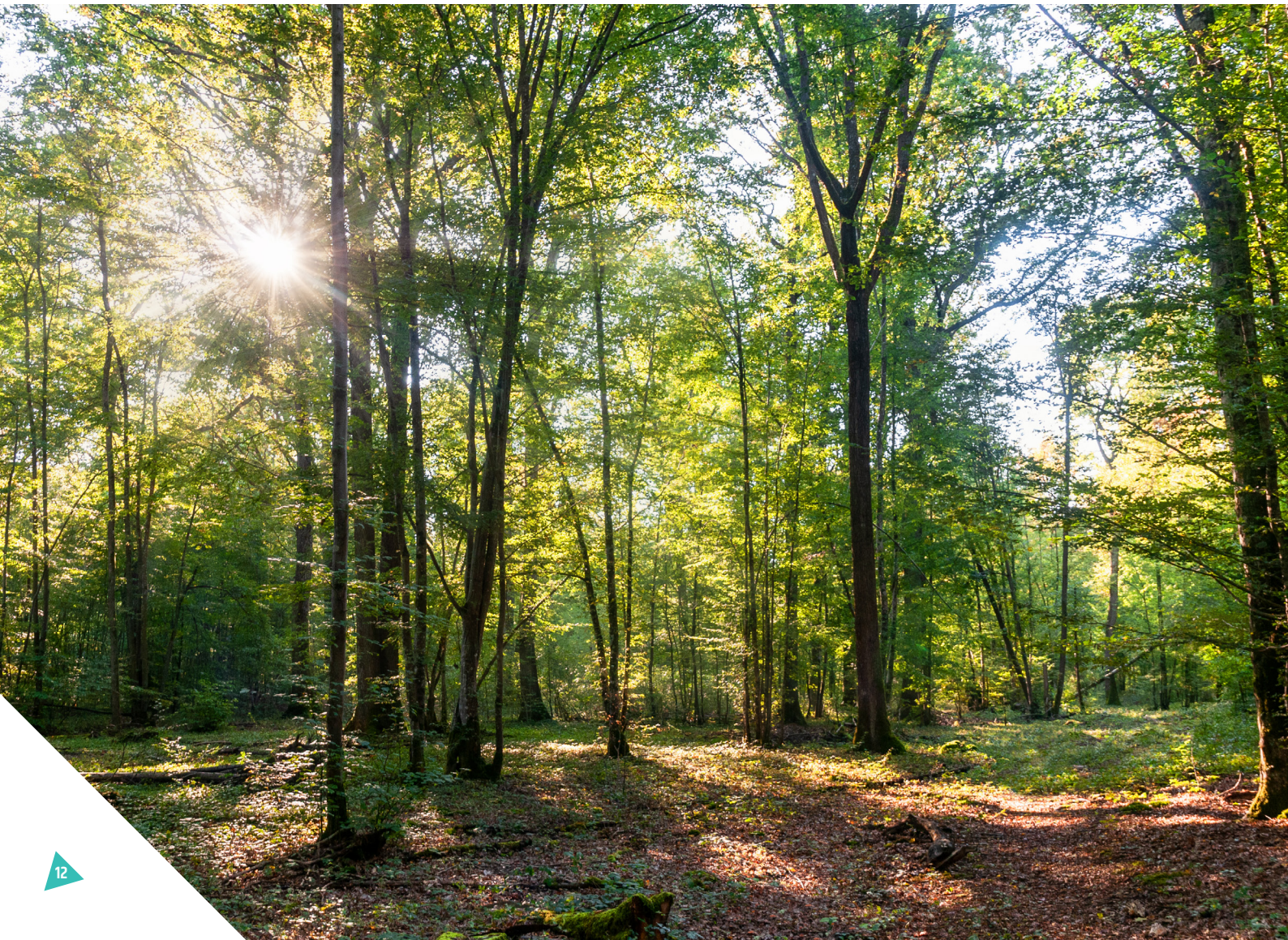
- Shift to balanced, sustainable healthy diets
- Reduce food loss and food waste
- Reduce methane and nitrous oxide emissions in agriculture
- Minimise dependency on production-related inputs
- Increase efficiency in extracting valuable resources
- Promote carbon sequestration in healthy and resilient forests
- Promote carbon sequestration on agricultural land in woody structures and soil
- Promote ecosystem restoration, and planting trees in urbanised areas
- Reduce net land take from about 0.5 ha per day to 0 ha per year

Finance

- Maintain public spending on projects that lead to and/or support sustainability transformation
- Attract sustainable financing for sustainable projects/investments with a particular focus on Luxembourg and the Greater Region
- Identify financial support for sustainable initiatives at the community level

Further information on the respective recommendations can be found in the report, in particular in Chapter 1.

In this first annual climate report for Luxembourg, the OPC has set the scene regarding Luxembourg's climate change situation and conditions. While first incremental steps have been taken to address the reduction of greenhouse gas emissions, the report highlights that existing policies need to be strengthened but also a more fundamental change in society will be necessary to transform Luxembourg to a sustainable and decarbonised society.



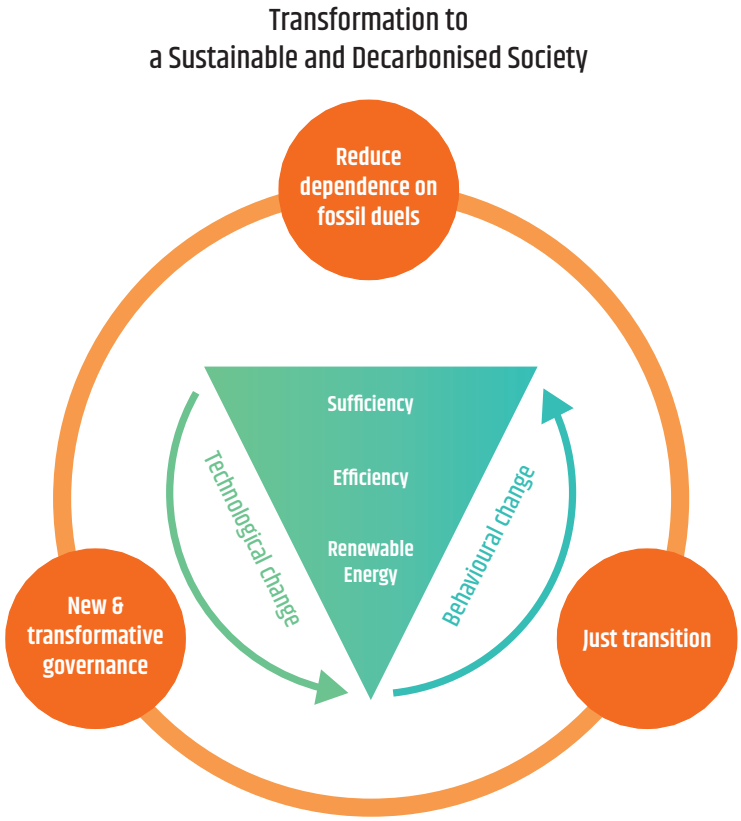
1 Principles for a rapid and just transformation towards a sustainable and decarbonised society

Luxembourg's climate law fixes a target of greenhouse gas emission reduction by 55% compared to 2005 by 2030 and achieving climate neutrality in 2050 at the latest. In order to achieve this, a national plan on energy and climate was developed in 2020 and a national adaptation strategy was decided in 2018 to fix concrete measures in the different sectors.

The latest official figures on greenhouse gas emissions[8] indeed show a reduction between 2019 and 2021, in part helped by the economic slowdown in 2020 during the COVID-19 pandemic. While the incremental measures contained in the national plan on energy and climate seem to imply a first move towards an emission reduction, further strengthening is necessary. In order to achieve the 2030 goal and, even more, the climate neutrality goal in 2050 at the latest, incremental measures will not be sufficient, and systemic changes need to be implemented as highlighted in the 6th Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC)[9].

The OPC recommends that further climate mitigation policies be guided by the following principles (see Figure 1.1).

Figure 1.1: Overview principles



1.1 Reduce dependence on fossil fuels

In all sectors, the Luxembourg economy's dependence on fossil fuels (coal, oil, and natural gas) should be strongly reduced. Not only is the decarbonisation process important in achieving the emission reduction targets, but also in reducing the dependence on imported fuels that have recently become very expensive.

Decarbonating the economy to meet targets such as a carbon neutral territory in Luxembourg in 2050 at the latest requires deep structural changes. The decarbonisation approach can be broken down into three main levers (see Section 4 for sectoral assessments):

- **Sufficiency**: popularise low-energy sufficient lifestyles
- **Energy efficiency**: increase the energy efficiency of the Luxembourg economy
- **Renewable energy production**: decarbonise energy production and imports

Traditionally, climate policies focus on the latter two. Both, energy efficiency improvements and *renewable energy production* are based on **technological change**. This can be incentivised by carbon pricing, energy performance standards, banning all forms of fossil fuel subsidies, and investments in renewables production capacity. These are important first steps but will not be sufficient.

To allow the adoption of low-energy and *sufficient* lifestyles, **behavioural change** as well as changes in the societal system are needed. The possibilities to make such changes should be accessible to all, not just to those segments of the population who can afford to take the time and make the monetary investments. This implies both raising awareness and opening up learning spaces for citizens and professionals about possibilities of change, as well as developing policies to ensure citizens and professionals are empowered to engage in making such changes, or experimenting with which solutions might work best in their specific situations.[10] Changes in the education system[11], including lifelong opportunities will also play a fundamental role in equipping citizens and professionals to contribute and cope with changes at work and at home. Particularly affluent consumers, both at individual and systemic level, private individuals and professionals, are contributing significantly to shaping and stabilising patterns of high emission (and consumption) behaviour[12]. In efforts to foster the transition, considering the demand side of emissions is thus at least as important in crafting mitigation policies, as are considerations of supply side emissions. To this aim policies promoting an understanding of possibilities for change, outreach and policies for empowerment on these topics are required for just transition. An emerging lever, which is intrinsically related to openness for change and learning as well, is the promotion of well-being policies, which have been positively correlated to sufficiency and climate-friendly lifestyles.

In a similar vein, it is necessary to **account for consumption-based emissions**. This means the counting of emissions needs to take into account the carbon embedded in imported goods as the transformation of the Luxembourg economy considers the need for a global decarbonisation (see Section 3 for detailed information). Similarly, in April 2022 Sweden's political parties agreed to set consumption-based targets that fully integrate this line of reasoning and will help to avoid delocalising carbon-intensive production out of high-purchase power countries as a carbon accounting trick.

1.2 Just Transition towards a climate-resilient development

The Intergovernmental Panel on Climate Change (IPCC) AR6 WGII[13] referred to "climate-resilient development" as "the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development for all." The rationale behind linking mitigation, adaptation, and sustainable development in this way is that the calls for rapid societal transformations towards a sustainable and decarbonised society are most effective if implemented in the wider context of the United Nations 17 Sustainable Development Goals (SDGs). These were launched with the overarching goal of 'transforming our world' in an integrated way. The AR6 WGII makes the following important points in that respect:

> "Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritise risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors and timeframes *(very high confidence)*."

"Climate resilient development is facilitated by international cooperation and by governments at all levels working with communities, civil society, educational bodies, scientific and other institutions, media, investors and businesses; and by developing partnerships with traditionally marginalised groups, including women, youth, Indigenous Peoples, local communities and ethnic minorities *(high confidence)*."

(Figure 1.2)

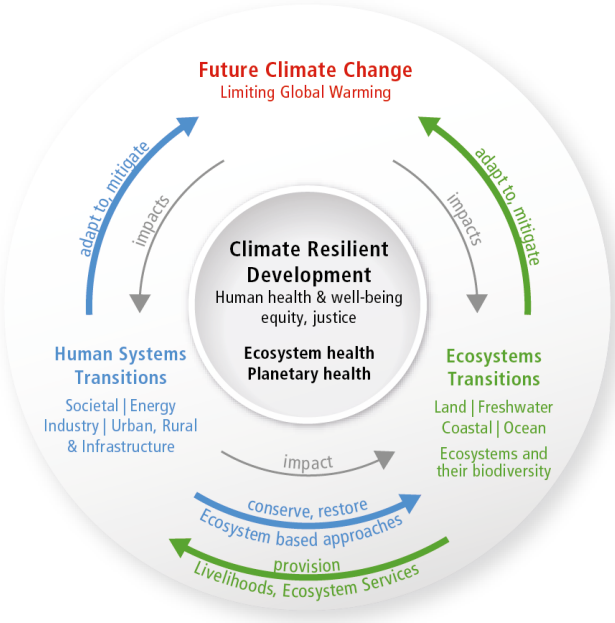


Figure 1.2: Meeting the objectives of climate resilient development thereby supporting human, ecosystem, and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology, and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society. Arrow colours represent human system interactions (blue), ecosystem (including biodiversity) interactions (green) and reduced impacts from climate change and human activities (grey). Source: IPCC AR6 WGII, Figure SPM.1 (b)[14]

The rapid and just transition or transformation of the Luxembourg economy and society towards climate resilient development needs to be "just" to be accepted by all. This can be achieved by targeted and proactive measures that ensure that any negative social, environmental, or economic impacts of economy-wide transitions are minimised, whilst costs are covered, and benefits are maximised for those disproportionally affected. These proactive measures include eradication of poverty, regulating prosperity and creating jobs in "green" sectors. In addition, the government, polluting industries, corporations, and those able to pay higher associated taxes, can pay for transition costs by providing a welfare safety net and adequate compensation to people, communities, and regions that have been impacted by pollution, are marginalised, and/or are negatively impacted by a transition from a high- to low- carbon economy and society.

When designing and implementing climate policies, at least three questions should thus always be raised in the context of just transformations[15]: What are the costs, benefits and risks associated with a policy and/or implementation measure? How are these costs, risks and benefits distributed amongst people with rights and responsibilities and other stakeholders in regard to the policy? And last but not least, how can we assess and evaluate the policies and their implementation in order to better understand whether the range of diverse impacts meets initial intentions or plays out in other ways as well? These questions relate to the distributional implications (mostly within a country itself) of policies, and are therefore important in the context of a just transition. For example, in the case of carbon taxes, the focus usually lies on the level of the taxes, whereas the use of the revenues attracts less attention – although it is shown that revenue recycling determines who profits and who loses out from a carbon tax. The same is true in the case of subsidy programmes, where usually little attention is given to how they are financed (e.g., through the state budget or a special levy). Similarly, setting standards for energy efficiency also requires careful analysis of who may benefit of a policy, who has to pay, and who carries risks. Luxembourg has comparably high standards for energy efficiency in newly built homes in the EU, e.g. by promoting passive houses. Subsidies contribute to reducing the problem of associated building costs, which can exclude some segments of the population from acquiring homes or apartments. However it is also important when it comes to distributional implications of the policies insuring that tenants would not suffer under higher rental prices. These considerations have implications not only for contents but also for the processes of policy making and governance at large[16].

What are the costs, benefits and risks associated with a policy and/or implementation measure?

How are these costs, risks and benefits distributed amongst people with rights and responsibilities and other stakeholders in regard to the policy?

How can we assess and evaluate the policies and their implementation in order to better understand whether the range of diverse impacts meets initial intentions or plays out in other ways as well?

1.3 New and transformative governance

The just transformation described above requires new and transformative governance: this means transforming not only the mix of policy instruments, but also the governance processes and structures in place. Traditional top-down, command-and-control policymaking processes are simply inadequate given the scale, scope, and complexity of the transformation required. The risk of sticking to traditional governance forms when societal transformation is necessary is the erosion of democratic governance and public trust and goodwill because of inadequate transparency, accountability, and (perceived) legitimacy.

We highlight three key areas for the development of legitimate transformative governance efforts across all stages of the policy cycle (from framing and agenda setting, to problem definition and policy development, and not forgetting policy implementation and evaluation):

- **Integrated governance** implies that governance processes facilitate coherent policy goals across multiple levels of governance (local-national-European) and across policy and societal sectors.
- **Participative governance** means that knowledge about policy problems (framing) and approaches to address these (policy instruments) is co-created with a wide range of communities, groups, citizens, and stakeholders, through explicitly open, transparent, and participative governance mechanisms, such as citizen's assemblies, citizen science projects and multi-stakeholder interaction processes. Not only must the governance structures be renewed for meaningful participation, but the knowledge architecture informing governance choices needs to be reframed.
- **Fair governance** means that the new transformative governance structures and processes alleviate the inequalities of access, resources and benefits associated with problem and solution framing (for example across generations, rural/urban communities, minority groups, people with disabilities, etc.).

A future OPC report will elaborate further on just transformations and transformative governance to navigate such changes in a democratic manner trying not to leave anyone behind.

1.4 Summary of Sectoral recommendations

The rapid and just transformation to a sustainable and decarbonised society requires action across all sectors of society. In the following, we provide recommendations on how to proceed with selecting sectors. The recommendations listed here are limited: they do not cover all sectors; they are not to be considered exhaustive within the sectors discussed and there is no hierarchy of importance attached to them. We also provide recommendations aimed to spur action along different timescales and at different levels of governance. What is important to note is that the recommendations aim to translate the principal goal of a rapid and just transformation to a sustainable and decarbonised society into urgent action in a selection of sectors.

Specifically, the decarbonisation approach comprises three main levers[17]:

- **Sufficiency:** popularise low-energy sufficient lifestyles
- **Energy efficiency:** increase the energy efficiency of Luxembourg's economy
- **Renewable energy production:** decarbonise energy production and imports

1.4.1 Buildings

Sufficiency

Reduce ambient temperature in homes, apartments and offices: At the time of writing this report, the most prominent is the voluntary energy savings campaign "Zesummen spueren, zesummenhaalen", that aims at reducing gas consumption this winter by 15% compared to the reference period 2017-2021. Such efforts should be continued after the energy crisis.

Reduce floor area per person: With Luxembourg holding the European record for highest energy use per dwelling[18], the room for improvement is immense. At 132 m^2/dwelling for 2.5 persons on average, surface area could be reduced to reach about 90 m^2 in 2050, based on a recent UNEP Resource Panel study[19]. The total surface area could be reduced partly by reclaiming unused office or parking garage space.

Efficiency

Promote resilient buildings: There is a large overlap between mitigation and adaptation measures in the buildings sector. When renovating buildings, they need to be prepared for climate extremes. Possible measures include the use of sustainable construction materials as well as adding green infrastructure around and on top of buildings. Finally, maladaptation (e.g., air conditioning) needs to be prevented.

Require landlords to invest in renovations of leased homes or apartments: House owners living in their own house have stronger incentives to renovate as this helps to save energy and carbon costs. In the case of landlords of leased homes or apartments, incentives to renovate are largely missing. An interesting example of such incentive would be to link the possibility for landlords to index the rents to the energy performance of the buildings they rent.

Make use of "special events": For example, when the new generation takes over a house or when tenants change, the situation is ideal to do renovations as the house or apartment is vacant.

Renewable Energy

Ban fossil heating systems: For example, the regulation for new buildings (see above) should also be implemented for existing buildings. It needs to apply whenever a heating system has to be replaced. Of course, this policy needs to be complemented with hardship rule in cases the replacement is not possible and financial support for households that cannot afford it.

1.4.2 Transport

Sufficiency

Land use and urban planning to reduce space for cars, either on roads or for parking: A very clear signal would be to ban the building of new roads, as has been done by the Welsh government[20].

Develop plans for a 15-minute city, where amenities and necessities are within a 15 minute walk or bicycle ride from residencies.

Promoting working from home instead of travelling to workplaces.

Efficiency

Incentivise the modal shift from a car-centric to a shared, soft mobility system: Shift to an integrated system connecting (renewable) public transport, bicycle infrastructure, safe infrastructure for pedestrians. Literature suggests that shifting away from cars can be accomplished by communicating about the positive sides of alternatives, as was done in Copenhagen, whose successful cycling communication never mentioned cars or climate change[21].

Spatial planning efforts to make it easier to benefit from the excellent initiative to provide free public transport, e.g., by making it easier for bicycles and pedestrians to connect to and use the public transport infrastructure and by making it more difficult for the private car to remain a central mode of transport, by, e.g.:

a. Expanding the public transport offer;
b. connecting to bicycle parking (bike and ride);
c. building more protected bicycle lanes and develop more pedestrian zones;
d. reducing speed limits to limit emissions, increase safety and reduce the time-incentive for car travel;
e. Implementing low emission zones and traffic calming infrastructure or increasing car-free zones.

Renewable Energy

Increase share of electric vehicles (EV) and ban fossil fuel vehicles: The banning of the sale of fossil fuel cars in the European Union (EU) is planned for 2035. Luxembourg could increase taxes on fossil fuel cars so as to make them less attractive compared to EVs to accelerate the transition before the ban. As a complementary measure, the subsidy for EVs could be continued and adjusted at a lower amount if necessary. The subsidy should be conditional on the subscription of an electricity contract supporting the increase of local renewable energy capacity to unlock the full decarbonisation potential of EVs.

1.4.3 Energy Systems

Sufficiency and Efficiency

Continue and strengthen the measures in place aiming for a reduction of final energy demand of between 40% and 44% by 2030 compared to the EU PRIMES[22] baseline. In addition, efforts put into place to reduce gas consumption this winter by 15% compared to the reference period 2017-2021 as highlighted by the campaign "Zesummen spueren, zesummenhaalen" should be continued after the energy crisis.

Renewable Energy

Increase the capacity of renewable energy production and thereby decrease the dependence on imports from foreign markets. Priority should be given to the increase of local capacity of clean electricity production, mainly from renewables, and to direct investments into capacity of renewable generation abroad. It is recommended not to rely on energy certificates (certificates of origin); but instead directly invest in buildingrenewable energy production capacity both on the national territory and abroad, which can consistently be allocated to national accounts.

Increasing the share of renewable power production, e.g., rooftop solar panels or the use of panels over agricultural production fields. Favour the combination of small-scale capacity in proximity to demand sources and mid-size power units for optimal trade-off between transmission losses and good production efficiency.

Reaction to current energy crisis

Financial support for vulnerable households and companies: In times of inflation and high energy prices, financial support for vulnerable households and companies is important. Such support must reach precisely those who needs the support most.

No subsidies to fossil energy: General subsidies to fossil fuels must be avoided at all times, as these directly counteract the CO_2 tax.

1.4.4 Food, Agriculture and Forestry

Sufficiency

Shift to balanced, sustainable healthy diets: A profound adaptation is required in individual and societal demands, looking at the types, quality and quantity of agricultural products that are purchased and used. A shift towards more plant-based diets would not only promise health benefits compared to consuming high levels of red meat, but additionally help to reduce the demand side option of reduced livestock in Luxembourg. Strategies to better align demand to the biophysical capacity of the Luxembourg territory will also have profound implications for land use for food and fibre production. An awareness-raising campaign on the relation between dietary and climate change and attention to affordability of regional, seasonal, and organically grown foods could be a first step in this direction.

Efficiency

Reduce food loss and food waste: Continue and accelerate the promotion of concepts behind the current "Anti gaspi" campaign, to reduce the food waste to minimum by consumers. In addition, raise awareness in the agricultural and gastronomy sector to reduce food lost. This will require profound and disruptive social innovations in the value chain and access to foods in particular by more vulnerable groups in society.

Reduce methane and nitrous oxide emissions in agriculture: For Luxembourg, 70-80% of methane emissions and nearly all nitrous oxide emissions are caused by agricultural activities. Measures aiming at reducing the livestock size in Luxembourg would lower the methane emissions, while the reduced use of fertilisers would reduce the nitrous oxide emissions.

Minimise dependence on production-related inputs, including chemical pesticides and fertilisers and fossil fuels that in themselves are energy-intensive to produce and the supply of which is becoming increasingly uncertain. More targeted measures to reduce dependence on chemical fertilisers and pesticides are needed with more targeted promotion of their replacement with nature-based solutions (NBS) such as those used in integrated pest management and modern agroforestry systems. Experimentation with different NBS in test beds should be actively encouraged and supported. More stringent standards for judicial use of chemical pesticides and fertilisers should be set for conventional farmers.

Increase efficiency in extracting valuable resources from to date unused by-products, such as looking at unused manure as a source of nutrients such as phosphate and closing other material flow loops in the logic of the circular economy.

Promoting carbon sequestration and self-regeneration capacity of ecosystems

Promote carbon sequestration in healthy and resilient forests: Reduced conversion of forests and afforestation, reforestation: The main driver here in Luxembourg is the conversion of forest and agricultural land to built-up areas. This is an important driver to slow down and stop sealing of land surfaces in order to keep the maximum of land surface possible that can contribute to carbon sequestration. Improved sustainable forest management: This measure should help national forests to move away from monocultures, which in turn would help to reduce their vulnerability to the impacts of climate change, increase biodiversity as well as carbon sequestration. Improve approaches to reach and engage private forest owners. Explore potential to restore built-up areas in Luxembourg to forested areas.

Promote carbon sequestration on agricultural land in woody structures and soil: In order to strongly increase the carbon sequestration in agriculture in Luxembourg, targeted measures and monitoring of humus content and soil life and its remuneration as ecosystem service provision are necessary, on and beyond farmland. Furthermore, to promote more woody structures on farmland, agroforestry potential should be explored and promoted. Agroforestry is not only of interest to increase carbon sequestration but also to help the agricultural sector to adapt to climate change, while helping to address biodiversity loss and promote local fruit production.

Promote ecosystem restoration, and planting trees in urbanised areas can help make cities more resilient to impacts of extreme weather events. Within settlements, the maintenance or creation of green spaces and planting of trees can increase carbon sequestration and also help to reduce local temperatures, thus helping to adapt settlements to climate change.

Reduce net land take from about 0.5 ha per day to 0 ha per year: by reducing the sealing of new surfaces for settlements, economic activities, or transport to zero or compensate by unsealing surfaces for newly sealed surfaces.

1.4.5 Finance sector

Align and strengthen national co-financing to industrial/economic investment programs, e.g., the "Fit for 55" and circular economy, both of which are pillars of sustainable industrial and economic development, and continue investment to *reduce Luxembourg's GHG emissions*, specifically in the industries analysed in this report.

Maintain public spending on projects that lead to and/or support sustainability transformation to help redesign industries according to sustainability principles. This includes substantial investment in jobs, training, and new sustainable job profiles.

Attract sustainable financing for sustainable projects/investments with a particular focus on Luxembourg and the Greater Region. Financial instruments of new design and *focus* (e.g., on sustainable industries in the Greater Region) could be developed, with blended finance and (more) equal risk sharing between private and public partners. Wherever reasonable, a regional focus further helps to shorten and strengthen supply chains, and make the regional economy more robust, more sustainable/more efficient, and less dependent.

Identify financial support for sustainable initiatives at the community level. This comprises long-term financial support for *community economies*[23], including, for example, their transition towards doing things alternatively (with focus on sufficiency and efficiency) and citizen-driven *energy communities*[24] to help pave the way for a clean energy transition.

2 Governance context

2.1 Climate Law and Policy in a global, European and Luxembourgish context

Luxembourg's policies are developed within a global and European context, some policies are agreed and implemented at EU level, some are agreed at EU level and need to be transposed and implemented at national level, and some are agreed and implemented at national level only.

2.1.1 The UN context

The United Nations Framework Convention on Climate Change (UNFCCC)[25], adopted in 1992, is the main overarching framework for global climate action, setting down the objective to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Paris Agreement[26], adopted in 2015, reinforces this commitment and lays out what needs to be done to respond to the climate challenge, and how. Article 2 of the Paris Agreement lays out the objective to hold the increase of 'global average temperature to well below 2 °C above pre-industrial levels' and to pursue 'efforts to limit the temperature increase to 1.5 °C'. Further, Article 4 states that this objective requires the 'global peeking of greenhouse gas emissions as soon as possible' and 'rapid reductions thereafter', aiming to achieve the goal of net zero emissions by the second half of the century. All these efforts are to be pursued in the context of sustainable development, efforts to eradicate poverty and to pursue climate justice[27]. The Paris Agreement also establishes a global goal on adaptation in Article 7, while Article 10 addresses the need to means of implementation and support to achieve the goals of the Agreement. Since the beginning of global climate processes, fairness and justice have been key principles in how to govern the response to climate change, while taking decisions in accordance with best available science.

2.1.2 The EU context

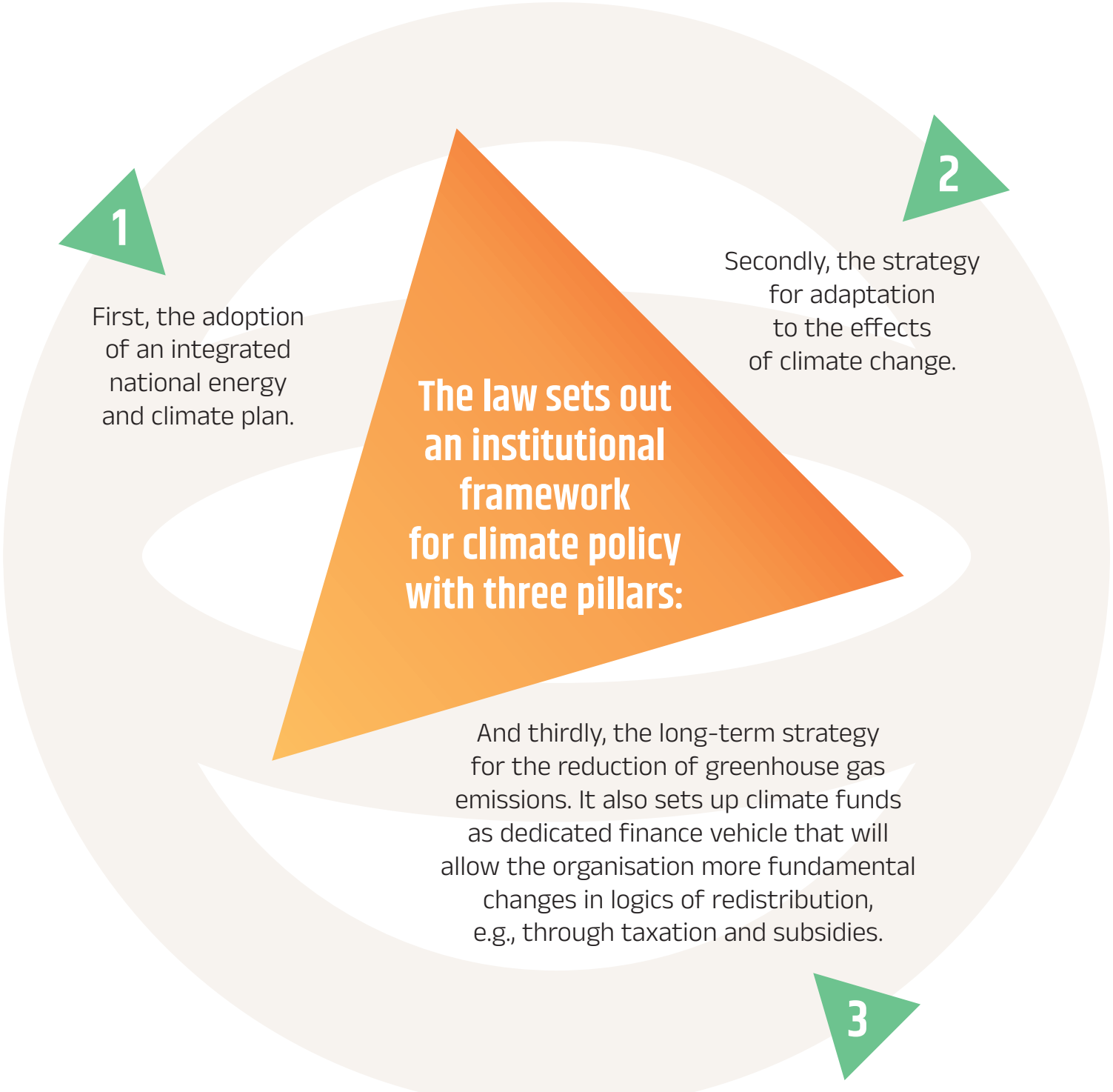
The publication of the European Green Deal in 2019 forms the EU's response to the goals of the Paris Agreement. The European Green Deal provides a roadmap for achieving climate neutrality (or net zero greenhouse gas emissions) by 2050, through integrated policies and projects, taking a systemic approach, and aiming for a just transition[28]. The European Green Deal thus brings together key principles of fair governance and integrated governance, by emphasising that no-one should be left behind in the transition to decarbonisation, and by emphasising the inherent interlinkages among policies and sectors and among social, environmental, climate mitigation, climate adaptation and socio-economic developments in the EU.

In 2021, the EU made climate neutrality legally binding for its member states under its Climate Law. It set an interim target of 55% emission reduction by 2030, compared to 1990 levels. The concrete legislation that will allow Europe to reach the Green Deal targets is laid down in the Fit for 55 package[29] that the Commission presented in July 2021. It includes the revision of existing legislation on emissions reduction and energy. Several policies and measures for achieving these GHG emissions reduction goals are agreed and governed at EU level, most notably the Emissions Trading System, which obliges large emitters/industrial installations across Europe (and also within Luxembourg) to purchase allowances for excess GHG emissions on a European-wide carbon market. At the same time, policies agreed at EU level, such as on efforts to increase the share of renewable energy efforts to improve energy efficiency, must then be transposed into national law to be implemented, with each member state contributing its share to the overall goal[30]. The EU is also working on achieving a circular economy by 2050, creating a sustainable food system and protecting biodiversity and pollinators. To finance the Green Deal, the European Commission presented in January 2020 the Sustainable Europe Investment Plan, which aims to attract at least €1 trillion of public and private investment over the next decade. Under the investment plan, the Just Transition Fund is designed to support regions and communities that are most affected by a green transition, for instance regions that are heavily dependent on coal.

Within the context of the Russian invasion of Ukraine in February 2022, the EU is reconsidering the current policy proposals. Under the Fit for 55 package, the proposed revision to the Renewable Energy Directive set an overall EU target of 40% share in renewable energy in final energy consumption in the EU by 2030. This target is being revised upwards to 45% as part of the overall commitment of the EU to shift away from a reliance on imports of fossil fuels from Russia. Greater emphasis is also being placed on measures to rapidly increase energy savings across the EU, under the REPowerEU strategy, presented in May 2022[31].

2.1.3 Luxembourg's Climate Law

Luxembourg's Climate Law[32] establishes a framework for a safe and healthy climate for humans and biodiversity, while continuing action to limit the rise in global average temperature to 1.5 °C above pre-industrial levels. In order to achieve this, it sets an economy wide mitigation target of 55% emission reductions by 2030 compared to 2005 and reaching "net zero emissions" in Luxembourg in 2050 at the latest. The law also excludes the possibility to develop nuclear energy as a means to achieve these objectives. Article 5 highlights five main sectors under focus for emission reductions: (1) energy, manufacturing, and construction industries; (2) transport; (3) residential and tertiary buildings; (4) agriculture; (5) waste and wastewater management.



2.2 Luxembourg: A general introduction

As one of the smallest member states of the EU, Luxembourg has a growing population of currently 600,000 residents in 2022. Its population has steadily increased by 10,000-12,000 people/year over the past three decades, thus experiencing the fastest population growth among the EU member states. Luxembourg comprises a land area of 2.586 km^2.[33] Recent population growth has put enormous pressure on both the built and social infrastructure, and the resulting pressure on land and its precious ecosystems is particularly salient.

Due to its small size and fast growth, Luxembourg offers an almost laboratory-like situation for problem identification and resolution, and is thus of particular interest as a case study of wider relevance within and beyond the EU. In principle, the short distance-to-power makes it possible to decide-implement-optimise very quickly. In practice, resistance to change still exists, as vested interests are at play in any social system. In short: social systems are inert. This situation offers, however, interesting insights and learning points for other countries where this cycle is longer.

In its geography, Luxembourg is mostly part of a large catchment area of the river Rhine (except for a small fraction of the territory in the Southwest that is part of the catchment of the Meuse), which requires a balanced and responsive Rhine River water governance system with neighbouring Germany, France but also Switzerland.

In political and administrative terms, Luxembourg has just two governance levels: it has no regional governance level, which is unique in comparison to other countries, and local interests define national policies directly as elected members of Parliament represent communes at the national level. In reality, this affects all areas of political decision-making, including planning and climate policies. Thus, it becomes clear that transition dynamics towards true sustainability play out and are enacted at the level of communities. Examples are energy communities and (alternative) community economies.

Socially, Luxembourg has a highly segmented population, with foreigners representing 47.2% of the resident population on the 1st of January 2021. The overall relatively high quality of life should allow residents to invest in mitigating (and adapting to) long-term climate change, for example, in terms of technology updates or behavioural change. In practice, however, people seem to be reluctant and fear to lose their privileged lifestyle. Anecdotal evidence, which informs this observation, requires, however, further in-depth analysis, which results, in turn, could be relevant to inform policies not only in Luxembourg but also in other countries. Overall, Luxembourg is highly diverse in its cultural and social composition and thus makes a compelling test-bed for new policies and behavioural change scenarios.

Administratively, Luxembourg as an entire country is a core part of the Greater Region, a test bed for European integration processes. Member regions of the Greater Region aspire to serve as "a model within Europe in terms of the free movement of people, goods and services." "The Greater Region is located in the heart of Europe, on the road and railroad axis that links the Mediterranean region to the North Sea. Its 11.6 million inhabitants spread over an area of 65,401 km^2. (about the same size as Lithuania), generate a GDP of 390 billion euros (figure for 2017) – 2.5% of the overall GDP of the European Union"[34]. With about 220,000 cross-border workers in this cross-border region, its huge number of commuters is also a peculiarity of the country, which needs to be associated with tensions in terms of mobility, emissions accounting, taxation, and misalignment/inconsistence of policies when crossing boundaries, to mention but a few.

In economic terms, and despite its limited size, Luxembourg contains an impressive number of industries. Many of them, however, are subsidiaries of multinational companies with headquarters (i.e., decision-makers) located abroad. This is certainly true for the banking sector. This means that important control structures over supply chains, standards, investment chains, but also employment are taken abroad. As a result, much of Luxembourg's economic decisions are taken elsewhere. Dependency from abroad, however, is not only obvious in terms of the work force and industry decision-making, but Luxembourg is also dependent on other European countries when it comes to energy provision. In summary, Luxembourg presents a setting of unique opportunities as a case study on which to develop a more comprehensive understanding on cross-scale interactions in transformation processes. Its significance as a case study encompasses a range of (partly overlapping and reinforcing) factors. For example, its small size and almost laboratory-like situation; the country's embeddedness in a large cross-border region; its resulting high dependencies on foreigners regarding its daily commuting cross-border work force, energy supplies, and headquarters of economic significance, but also a highly successful financial centre of global reach with means and knowledge to help finance the transformation task towards sustainability. This lens helps identify factors that support or hinder individual and concerted action, e.g., for changes in land use, agriculture, transportation and other sector of significance introduced and critically discussed in this report.

2.3 Climate and Climate Change in Luxembourg

According to the Köppen Climate classification, the climate in Luxembourg can be characterised as a temperate oceanic climate (cfb) with mild winters and comfortable summers (coldest month averaging above 0 °C, all months with average temperatures below 22 °C and at least four months averaging above 10 °C).

There is unimodal distribution of the long-term annual means temperatures, with the lowest long-term mean values occurring during January (0.9 °C for the period 1961-1990 and 2.1 °C for the period 1991-2020) and the highest air temperature in July (17.3 °C for the period 1961-1990 and 18.4 °C for the period 1991-2020). Since the dawn of temperature measurement in Luxembourg (1838), the absolute minimum and maximum air temperatures ever recorded were -23.5 °C (2 February 1956) and 40.8 °C (25 July 2019).

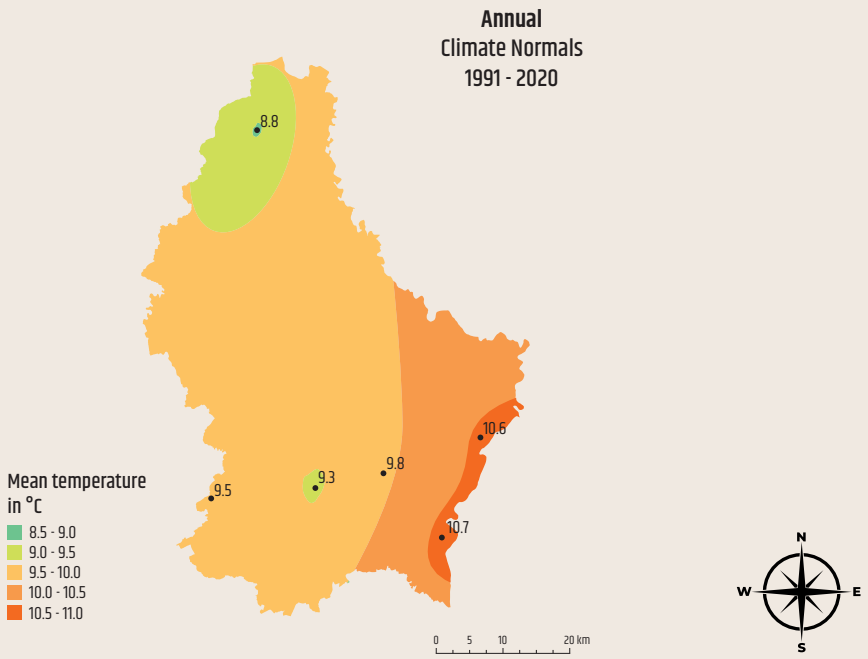


Figure2.1: Long-term mean values (1991-2020) of yearly air temperature, Sources: ASTA, MeteoLux

The regional distribution of precipitation shows higher regional variability. A general gradient from the North-West to the South-East of the country can be noted, with highest annual average values recorded in Roodt (1022.2 mm) and lowest values in Remich (711.8mm) for the time period 1991 – 2020.

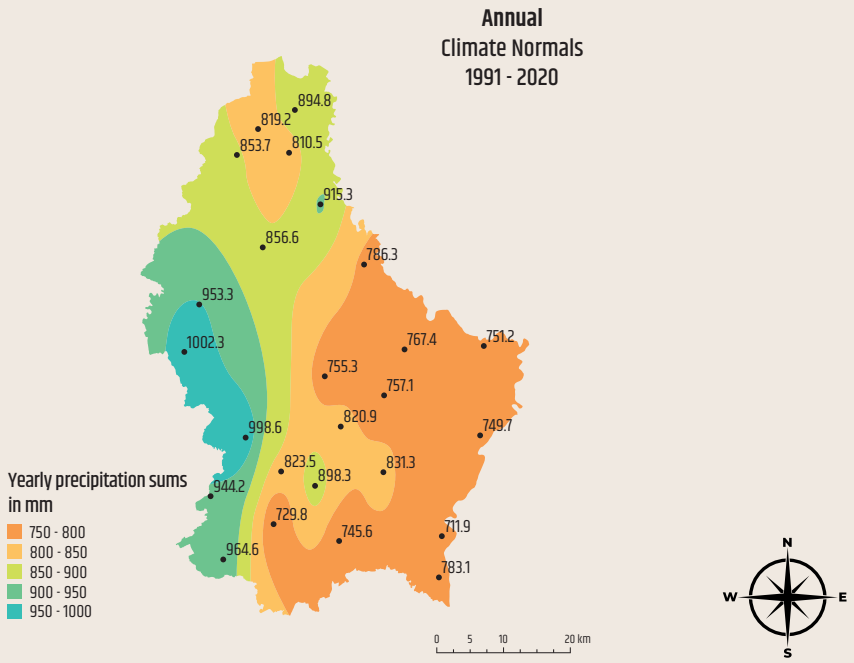


Figure2.2: Long-term mean values (1991-2020) of yearly precipitation, Sources: ASTA, MeteoLux

From 1990 onwards, the annual mean temperature started to increase rather sharply, reaching around +1.5 °C compared to pre-industrial age. The 10 warmest years are all in the period 2002-2021 and each of the last three decades has been successively warmer than any previous decade since 1840. The 1.5 °C increase in Luxembourg is faster than the global increase of 1.09 °C over a similar period as assessed by IPCC WR6 WGI[35]. This faster increase is to be expected as land surfaces are warming faster than the oceans. Further analysis of the data suggests that the average air temperature in Luxembourg has increased during the winter seasons, coupled with longer frost-free periods, and during summer with increased number of heat waves.

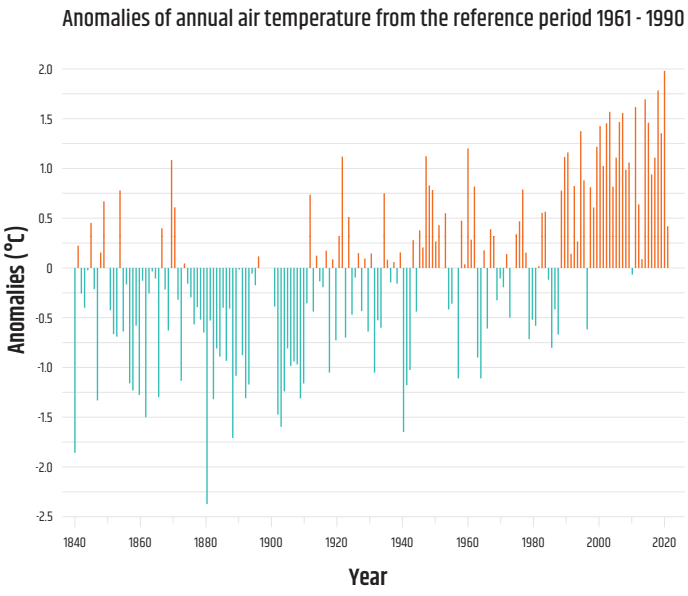


FIGURE 2.3 – Anomalies of annual air temperature compared to the reference period 1961-1990 for Luxembourg from 1838 to 2021, Sources: ASTA, MeteoLux, Note: The discontinuity in the red line (between 1896 and 1899) represents a gap in the data.

According to analyses based on the data from the national meteorological service of the Administration of Technical Agricultural Services (ASTA), precipitation has also changed over time, especially seasonally. Thus, there is significant decrease in spring and slightly significant increase in winter. However, the variations from one year to the next are less significant, so it is difficult to deduce a trend for yearly precipitation.

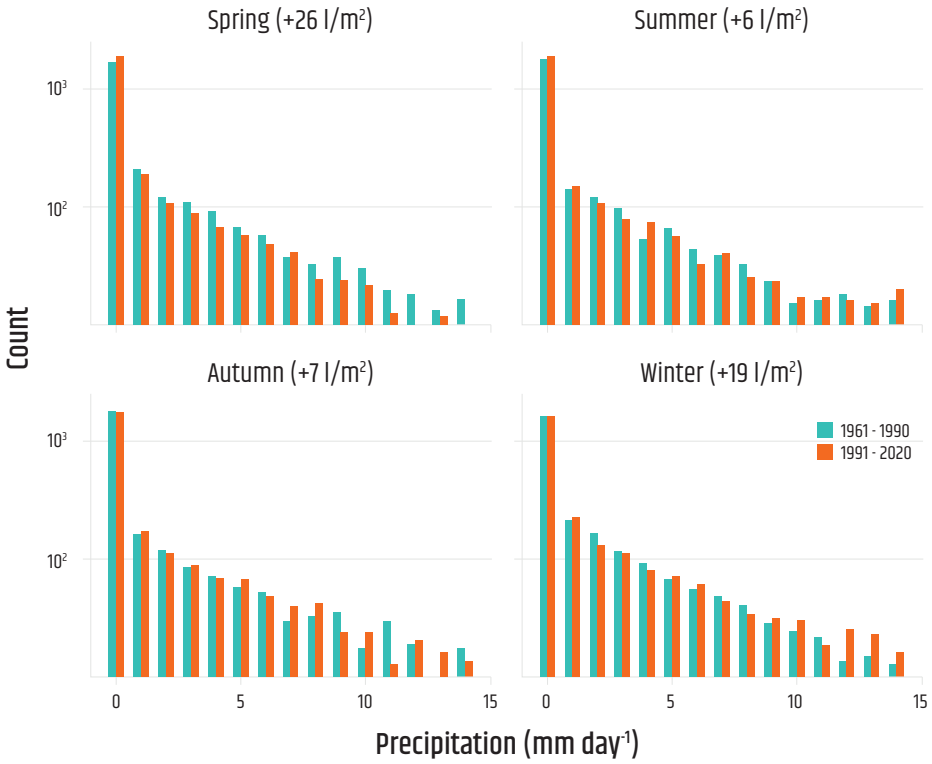


FIGURE 2.4 – Evolution of seasonal precipitations for the reference periods 1961 – 1990 and 1991 – 2020 (Luxembourg-city). Source: ASTA

Furthermore, changes in temperature and precipitation have an impact on hot and cold extremes, as well as on droughts.

Rising temperatures favour evaporation and evapotranspiration and hence droughts which are indicated in Figure 2.5 by an index higher than 0.5. We note that there has been a significant increase in the drought index for the months of April to November (except for July). For the period 1961-1990, only June and July with an index greater than or equal to 0.5 on average, while for 1991-2020, 10 months (except January and December) were marked by droughts.

But not only droughts are increasing: All hot extremes, such as hot nights and days, tropical nights, summer days, heatwaves, etc. tend to become more frequent and pronounced. Whereas cold extremes, like cold nights and days, frost days, ice days, etc. are decreasing over the time.

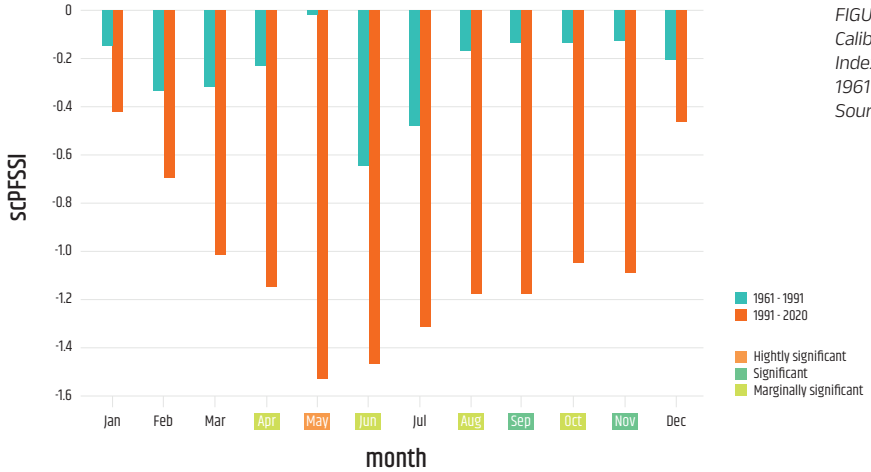


FIGURE 2.5 – Drought index (Self-Calibrated Palmer Drought Severity Index, sc-PDSI) for the time periods 1961 – 1990 and 1991 – 2020. Source: ASTA

2.4 The financial industry in Luxembourg

Finance is often seen the *key in unlocking strategies* to mitigate (and adapt) to climate change and related societal and economic challenges. However, Luxembourg's finance industry – and its international financial centre (IFC) for that matter – remain a contested policy field in its quest for future sustainability direction and economic income generation and an important means of foreign policy.

Luxembourg's IFC has longstanding experience, especially in the investment fund and bond industries, besides others. Both funds and bonds are preferred financial instruments for patient capital and comparably long-term investment horizons needed for a sustainable and just transformation. Luxembourg prides itself being a world-leading *green* financial centre.

Green finance usually has a strong, often exclusive, ecological, and environmental focus. *Sustainable finance* aims at financing projects that serve a more holistic societal wellbeing, including the provision of environmental benefits in the broader context of climate change and environmentally sustainable development. This is informed by the *UN SDGs* and the *European Green Deal*. A set of standards of environmental, social, and governance (ESG) criteria guides a whole financial eco-system in sustainable (and responsible) investing. The *EU's Taxonomy for Sustainable Activities* is a technical classification system and official framework for assessing ESG performance and for consistently categorising sustainable investments and investment products. Although not an industry compliance standard, the Taxonomy still obliges explicitly classified *sustainable* investments to disclose to what degree a financed corporation/project complies with ESG.

Not least against the background of the current energy crisis, the Taxonomy itself has morphed into a (political) battleground of competing and vested interests of countries and private stakeholders. One example is the designation of fossil energy sources like nuclear and natural gas as *sustainable* investments, in their function as bridging energy sources. It makes the EU Taxonomy a political compromise that leans more towards greenwashing rather than to its original, scientifically conscious, aims and "excellent guidance for bond issuance and bank lending worldwide". The disunity over the taxonomy has wide-ranging consequences, not only for the financial industries but also for law and regulations that seek to direct investment to projects concerned with tackling the loss of biodiversity, desertification, social inclusion and equality, and sustainable resource use more general. This politicised conflict is also unfolding in Luxembourg' IFC and Luxembourg's huge financial export industry.

Besides **exporting** financial services, government initiatives for **domestic** investment in Luxembourg's sustainability, often under the leadership of the Ministry of Finance, are laudable. They comprise, for example:

1) Luxembourg Sustainability Framework & Bond[36]:

In September 2020, Luxembourg published the first European framework for sovereign sustainability bonds[37], which focuses on both environmental and social aspects. In line with this framework, the Grand Duchy of Luxembourg issued its first EUR 1.5 billion sustainability bond in September 2020.

2) International Climate Finance Accelerator (ICFA)[38]:

Co-created in May 2018 by the Luxembourg Ministry of Finance and Ministry of the Environment and 10 partners from the private sector, the ICFA is part of the climate finance strategy of the Luxembourg government. It is a unique two-year programme that supports emerging climate impact fund managers. Each year, the ICFA selects a cohort of four fund managers and provides them with financial support for fund design, a guaranteed working capital loan from a bank for the fund, training workshops, coaching, and a physical workspace. There are currently 28 fund projects in the ICFA program, providing the opportunity to raise more than €1.5 billion in climate finance.

Luxembourg's financial and financing initiatives further entail international engagement, often coupled with international development aid.

3) Luxembourg-EIB Climate Finance Platform (LCFP)[39]:

The LCFP is an initiative of Luxembourg and the European Investment Bank (EIB) to mobilise and support investment in international climate finance. Equity investments here are made in subordinated tranches of multi-tiered funds. These funds then invest in companies in emerging economies involved in climate change mitigation (and adaptation) projects.

4) Forestry and Climate Change Fund (FCCF)[40]:

The FCCF invests in the sustainable management of degraded and secondary forests in Central America, providing a reliable source of income and enabling forest regeneration and protection. The objective is to invest directly and indirectly in a portfolio of forestry companies, community forestry companies and owners of smaller forests that focus on the management of secondary and degraded forests.

Hosting European public financial institutions like the European Investment Bank (EIB) and the European Investment Funds (EIF), Luxembourg is also a centre of excellence for blended and/or public-private financing instruments. Recently, the Commission and the EIB signed an agreement on the *Public Sector Loan Facility*, the third pillar of the *Just Transition Mechanism*, which is part of the *European Green Deal* to achieve EU climate neutrality by 2050. It will pave the way for public sector entities in the EU territories and regions that need most support in Europe's transition to a climate-neutral economy to benefit from €1.5 billion grants from the EU Commission and €10 billion of EIB loans[41].

Based on this very first assessment of Luxembourg's large, diverse financial industry, the OPC sees much opportunity to take an analytical deep dive into activities of the private sector of its financial industry to support growth and prosperity of the sustainability strategy linked with the UN SDGs and the European Green Deal. Our recommendations are therefore designed to further encourage the laudable government approaches to assist sustainable and climate change initiatives with patient capital.

General recommendations for the financial sector

Align and strengthen national co-financing to industrial/economic investment programs, e.g., the "Fit for 55" and circular economy, both of which are pillars of sustainable industrial and economic development, and continue investment to *reduce Luxembourg's GHG emissions*, specifically in the industries analysed in this report.

- **Maintain public spending on projects that lead to and/or support sustainability transformation** to help redesign industries according to sustainability principles. This includes substantial investment in jobs, training, and *new sustainable job profiles*.
- **Attract sustainable financing for projects/investments with a particular focus on Luxembourg and the Greater Region**. Financial instruments of new design and *focus* (e.g., on sustainable industries in the Greater Region) could be developed, with blended finance and (more) equal risk sharing between private and public partners. Wherever reasonable, a regional focus further helps to shorten and strengthen supply chains, and make the *regional economy* more robust, more sustainable/more efficient, and less dependent.
- **Identify financial support for initiatives at the community level**. This comprises long-term financial support for *community economies*[42], including, for example, their transition towards doing things alternatively (with focus on sufficiency and efficiency) and citizen-driven *energy communities*[43] to help pave the way for a clean energy transition.

3 Consumption and production emissions and sequestration

The analysis in chapters 3.1 and 3.2 builds on findings from the Phase 1 report of the "Luxembourg in Transition 2050" international consultation[44].

3.1. "Territorial" versus "consumption" GHG emissions

GHG emissions are primarily accounted for with a *territorial* approach, whereby national inventories of imported fossil fuels, agricultural processes, land use, industrial processes and products use (IPPU) as well as waste & wastewater related emissions are compiled to calculate *production-based* emissions (UNFCCC, 2020)[45]. In highly globalised or small countries, this approach may not be as representative of the actual *consumption-based* emissions, where territorial emissions are adjusted with GHGs embodied in trade, imports, and exports. Seminal examples are Switzerland, which imports the (net) equivalent of twice its production-based emissions every year, and China or India which are net exporters of GHG emissions, as they sell abroad more embodied carbon than their population uses[46]. Furthermore, to account for the 200,000 cross-border commuters technically "consuming" in the Grand Duchy every day, resident-only emissions should be separated to gather a fair view of their contribution.

Using a *top-down* approach and the multiregional input-output database EXIOBASE3.8 [47], in Figure 3.1 we illustrate the difference between production-based and consumption-based accounts for 2019.

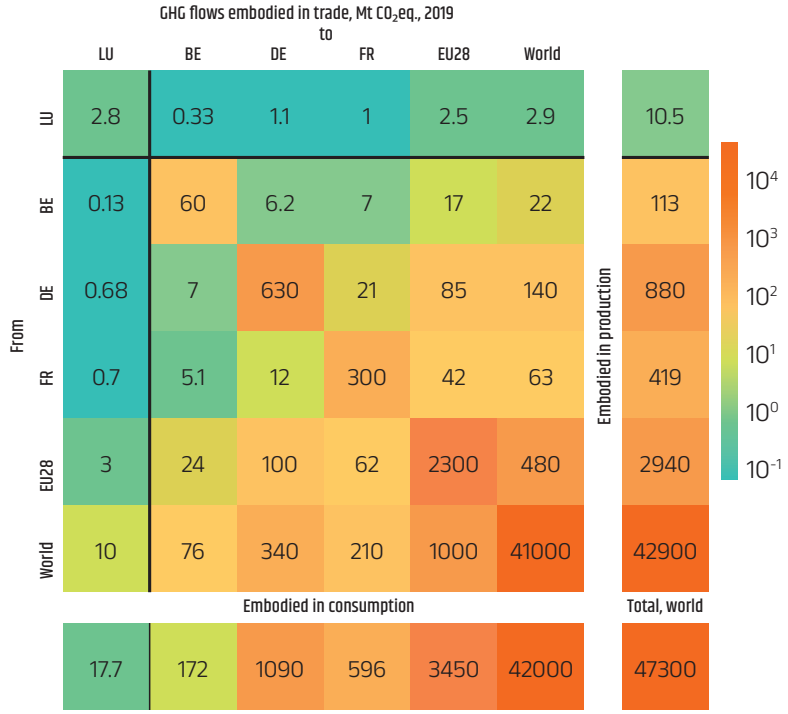


Figure 3.1: Embodied greenhouse gas emissions. Small errors in the totals are due to rounding. Luxembourg Institute of Science and Technology calculations (Lead author: Thomas GIBON)

In the first row, total territorial (production-based) emissions for 2019 equal 10.5 Mt of CO_2eq., which correspond to the declaration to UNFCCC. However, Luxembourg re-exports a large quantity of embodied energy and carbon emissions, also due to a high amount of industry relative to its size. It is estimated that only 2.8 Mt of CO_2eq. are emitted in Luxembourg for Luxembourgers' final consumption (see the LU-LU cell in Figure 3.1).

In the first column, we obtain an estimation of the total consumption-based emissions, where to LU-LU emissions are added all imports, estimated at 14.9 Mt CO_2eq., which finally leads to total consumption-based emissions of 17.7 Mt CO_2eq.

In order to separate the *footprint of residents*, the top-down consumption-based calculation is not satisfactory: residents only represent a small share of electricity consumption or fuel use (due to fuel sold to non-residents and cross-border commuters). A bottom-up approach is needed, whereby every household consumption category from official accountings (e.g., Eurostat, statistiques.lu) is analysed and characterised in terms of life cycle GHG emissions. The total consumption-based emissions following a bottom-up calculation approach amounts to 7.9 Mt CO_2eq. (13.2 t CO_2eq. per resident in 2019), as detailed in Figure 3.2.

Production-based:
17.7 Mt CO_2eq.

Consumption-based:
10.5 Mt CO_2eq.

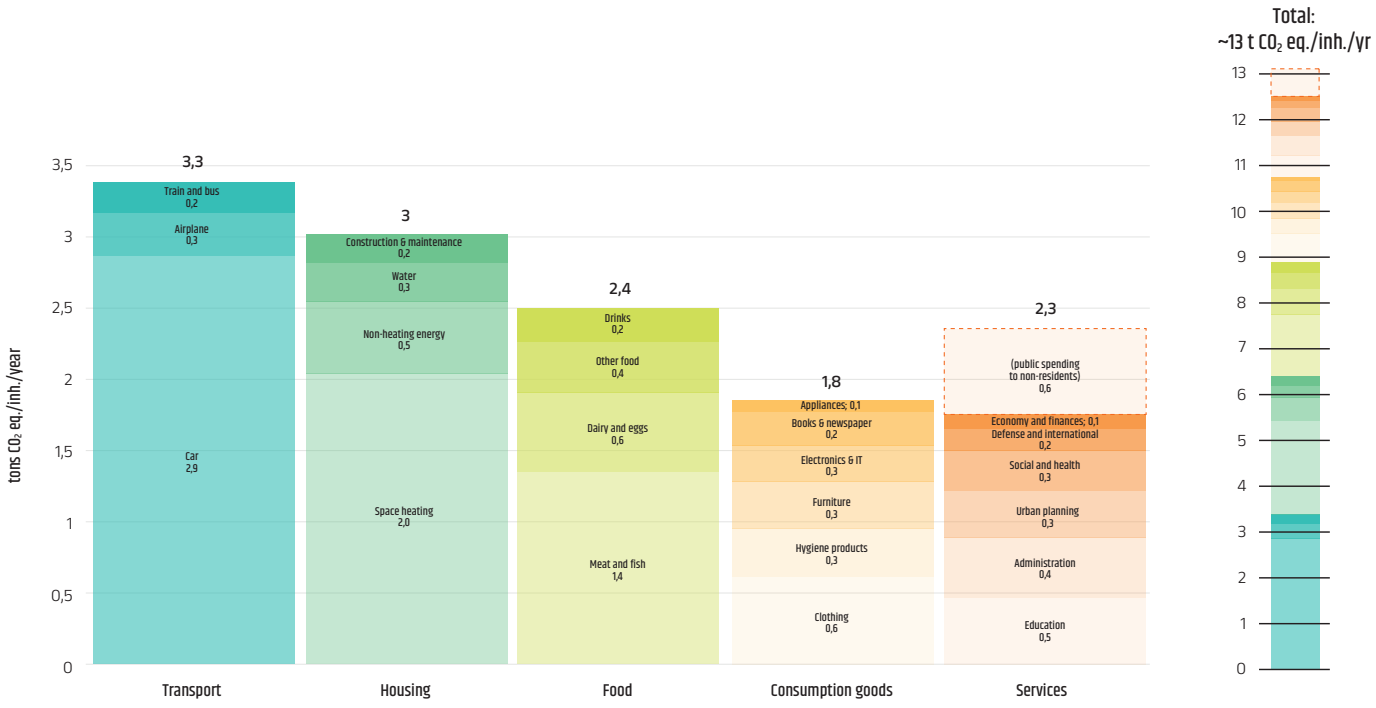


Figure 3.2: Carbon Footprint of Luxembourg (consumption-based bottom-up approach). Luxembourg Institute of Science and Technology calculations based on STATEC, ecoinvent 3.6, myclimate.lu and Carbone4 data. (Lead author: Elorri IGOS)

Transport is the main contributor, as car use dominates mobility in Luxembourg, and residents travel regularly by plane. Trains and buses only constitute a small share of the footprint: their use is not yet widespread, and their per-passenger impact is low. Next, **housing** contributes 25%, mostly through energy use for heating and appliances (more than 1 Mt of emissions in Luxembourg originate solely from fuel oil and gas for residential heating - 10% of national emissions). **Food** impacts are also high, as Luxembourgers consume 86 kg of meat per person annually, of which 15 kg is beef - a GHG-intensive food item[48]. The next category is **consumption goods**, including hygiene products, clothes, IT, and books, whose manufacturing, transport and/or use require energy and generate emissions. Finally, **public services**, including education, research, healthcare, police, and administration account for about 1.5 tonnes per resident. Luxembourg's **energy** landscape is a good illustration of the degree of interdependence it entertains with neighbouring countries. In 2019 the Grand Duchy produced no more than 15.9% of its total electricity consumption of 6.6 TWh, corresponding more or less to the share of residential consumption (14.6%), with the rest used by commercial activities as well as heavy industries[49]. As a result, most of the electricity is imported from neighbouring countries, which follow very different decarbonisation pathways. Additionally, 4.6 million tonnes of oil equivalent (42 TWh) of fuels is imported annually by Luxembourg, mostly to meet the demand of long-distance trucks and airplanes, but also that of the increasing number of Greater Region commuters driving over the border twice a day[50]. All consumption considered, 95% of Luxembourg's energy supply is imported.

The bottom-up consumption-based emissions of residents calculated above is then separated from the top-down accounting, leading to a reconciliation in the Sankey-flow diagram of Figure 3.3. We can observe then the estimated fraction of total emissions related to consumption (17.7 Mt), which is due to the consumption of non-residents (3.93 Mt) and the fuel sold to non-residents (4.80 Mt).

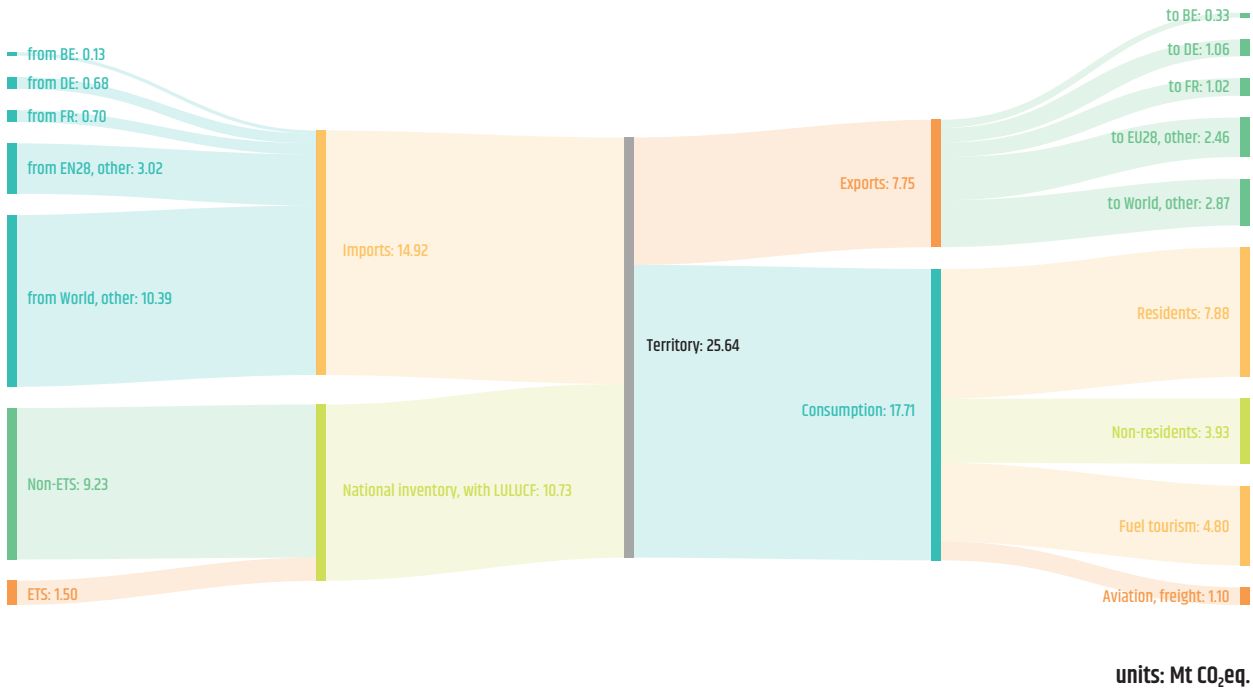


Figure 3.3: Reconciliation of top-down vs. bottom-up accounting approaches and production vs. consumption accounting. Luxembourg Institute of Science and Technology calculations. (Lead author: Thomas GIBON)

The bottom-up consumption-based emissions of residents calculated above is then separated from the top-down accounting, leading to a reconciliation in the Sankey-flow diagram of Figure 3.3. We can observe then the estimated fraction of total emissions related to consumption (17.7 Mt), which is due to the consumption of non-residents (3.93 Mt) and the fuel sold to non-residents (4.80 Mt).

3.2. The importance of broadening the perspective beyond CO_2 emissions

While the reduction in GHG emissions is the driving force and principal goal of climate policy, special care should be given to consider the impact of the required policy interventions on other environmental and social dimensions. These should form a constraint on the type of interventions imposed and serve to make the decarbonisation path resilient in the ecological and social dimensions. Changes in production, consumption, and behaviour are costly and require a large collective effort. **A transition of this scale is to a large extent non-reversible**. Embarking on a transition path that is inherently unsustainable in terms of our impact on other environmental resources or on human health would require a reset at a later stage when we encroach upon the limits along those sustainability dimensions. Ultimately, reducing GHG emissions is a goal that is in service to maintaining the wellbeing of humanity and the environment for generations to come. Table 1 presents a few additional indicators, and their value for 2020, measuring endpoints rather than intermediate effects, having minimal overlap of each other and maximal coverage across sustainability dimensions. These indicators follow a consumption-based approach, i.e., account for emissions embodied in final consumption, and are not supposed to be exhaustive.

Phosphorus (P) emissions are costly to society for two reasons, because they contribute to freshwater eutrophication and because the majority of phosphorus for mineral P fertilisers is mined with global deposits rapidly depleting. The air pollution indicator combines the amount of nitrogen oxides, sulphur oxides, and particulate matter emissions (2.5 µm) and converts these into a single indicator measured in disability-adjusted life years (DALYs). Finally, material use is also accounted for, as the lump sum of all materials extracted from nature annually to meet the final demand of Luxembourgers. This indicator measures the resource sustainability of conventional lifestyles, which currently lack circular economy solutions at scale. As materials in this indicator are uncharacterised, it is biased towards material-intensive activities such as construction and does not take into account the criticality of certain specialty metals or precious ores; these aspects can however be addressed qualitatively.

Table 1: Environmental boundaries and social/environmental foundation. LIST calculations (Lead author: Thomas GIBON)

Domain	Indicator unit	Status 2020		
		Production (from LU)	Consumption (in LU)	Consumption (by LU res)
GHG emissions	t CO_2eq. /capita/year	17	22	13
Marine eutrophication	kg N/capita/year	5.6	39	20
Freshwater eutrophication	kg P/capita/year	9.8	23	12
Bluewater use	m^3/capita/year	103	583	292
Air pollution	DALY/1000 capita/year	14	21	11
Material use	tons material/capita/year	0	32	16

4 (Cross-)Sectoral approaches to reduce greenhouse gas emissions

The rapid and just transformation to a sustainable and decarbonised society requires action across all sectors of society. In the following, we provide recommendations on how to proceed in a selection of sectors. The recommendations listed here are limited: they do not cover all sectors; they are not to be considered exhaustive within the sectors discussed; and there is no hierarchy of importance attached to them. We also provide recommendations aimed to spur action along different timescales and at different levels of governance. What is important to note is that the recommendations aim to translate the principal goal of a rapid and just transformation to a sustainable and decarbonised society into urgent action in a selection of sectors.

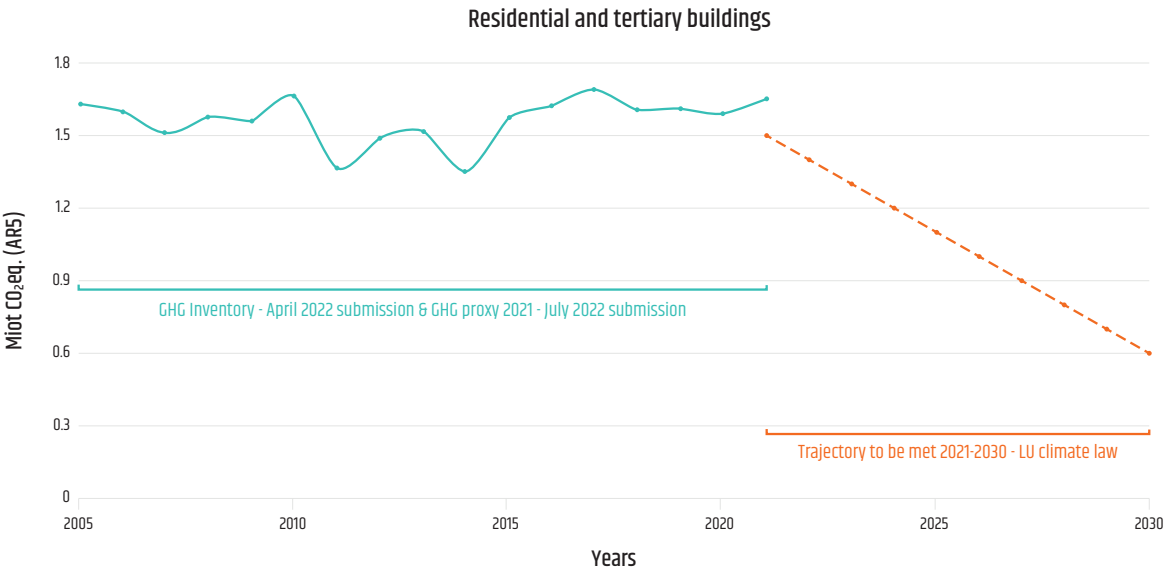
Specifically, the decarbonisation approach can be decomposed into three main levers[51]:

- **Sufficiency**: popularise low-energy sufficient lifestyles
- **Energy efficiency**: increase the energy efficiency of the Luxembourg economy
- **Renewable energy production**: decarbonise energy production and imports

4.1. Buildings/Housing

4.1.1 Past emissions and reduction targets

Figure 4.1: Emissions from residential and tertiary buildings and trajectory to be met according to Luxembourg's climate law.



Notes: The figures from 2005 to 2021 (2021 still provisional) are calculations of GHG emissions from the GHG inventories prepared according to the IPCC guidelines and submitted annually to the UNFCCC and the European Commission. These calculations are the ones that count for Luxembourg's national and international commitments. The blue dotted line represents the sectoral target for the building sector according to the Luxembourg climate law. Values are expressed in millions of tonnes of CO_2eq. based on IPCC 100-year global warming potentials (GWP100) from the 5th Assessment Report.

Figure 4.1 shows the historic emissions as well as the future emission targets for the Luxembourgish buildings sector. It shows that in the past 15 years, emissions in the buildings sector more or less stagnated, reaching a level of 1.7 Mt CO_2eq. in 2021. This is clearly above the target of 1.5 Mt CO_2eq. Comparing the stagnating emission trajectory from the past with the target path for the future, it is clear that substantial additional policy measures will be needed.

Due to long lifetimes, buildings do not allow as fast a transition as in other sectors (mobility, services, communications). The lock-in effect is therefore high and early action crucial. At the same time, the long-term impact reduction potential of housing is also significant.

4.1.2 Need for transformation

In the past, the government has implemented a broad set of climate policies in the buildings sector including a carbon tax, subsidies for house renovations or energy performance standards. Unfortunately, these do not seem to be sufficient. The following transformations are needed to drastically reduce GHG emissions in Luxembourg's buildings sector:

Sufficiency

The vision of sufficiency in the buildings and housing sector requires choices and policies to reduce the space need per person as well as a temperature reduction:

- **Reduce ambient temperature in homes, apartments and offices**: At the time of writing this report, the most prominent is the voluntary energy savings campaign "Zesummen spueren, zesummenhaalen", that aims at reducing gas consumption this winter by 15% compared to the reference period 2017-2021. Such efforts should be continued after the energy crisis.
- **Reduce floor area per person**: With Luxembourg holding the European record for highest energy use per dwelling[52], the room for improvement is immense. At 132 m^2/dwelling for 2.5 persons on average, surface area could be reduced to reach about 90 m^2 in 2050, based on recent UNEP Resource Panel study[53]. The total surface area could be reduced partly by reclaiming unused office or parking garage space.

Efficiency

To increase energy efficiency in the buildings sector, it is nothing new that the retrofit rate (percentage of retrofitted buildings per year) needs to be increased. When designing new policy measures the focus should lie on:

- **Promote resilient buildings**: There is a large overlap between mitigation and adaptation measures in the buildings sector. When renovating buildings, they need to be prepared for climate extremes. Possible measures include the use of sustainable construction materials as well as adding green infrastructure around buildings. Finally, maladaptation (e.g., air conditioning) needs to be prevented.
- **Require landlords to invest in renovations of leased homes or apartments**: House owners living in their own house have stronger incentives to renovate as this helps to save energy and carbon costs. In the case of landlords of leased homes or apartments, incentives to renovate are largely missing. An interesting example of such incentive would be to link the possibility for landlords to index the rents to the energy performance of the buildings they rent.
- **Make use of "special events"**: For example, when the new generation takes over a house or when tenants change, the situation is ideal to do renovations as the house or apartment is vacant.

Renewable energy

The residential sector is today mostly heated with fossil fuels. To reach the climate targets, the heating systems need to be changed to carbon-neutral heating systems, including heat pumps or district heating systems.

In the case of new buildings, the current regulation is very strict on new buildings, which will be subject to an indirect ban on fossil fuel heating systems from 01.01.2023 onwards. Specifically, the energy performance of buildings regulation[54] prescribes a limit value on the primary energy demand of a planned new building that needs to be respected in order to obtain a building permit. From 01.01.2023 onwards, this limit will not be able to be met with a fossil heating system. In other words, though there is no explicit ban on fossil heating systems, due to the limit on the primary energy demand of a new building, the regulation works as an indirect ban.

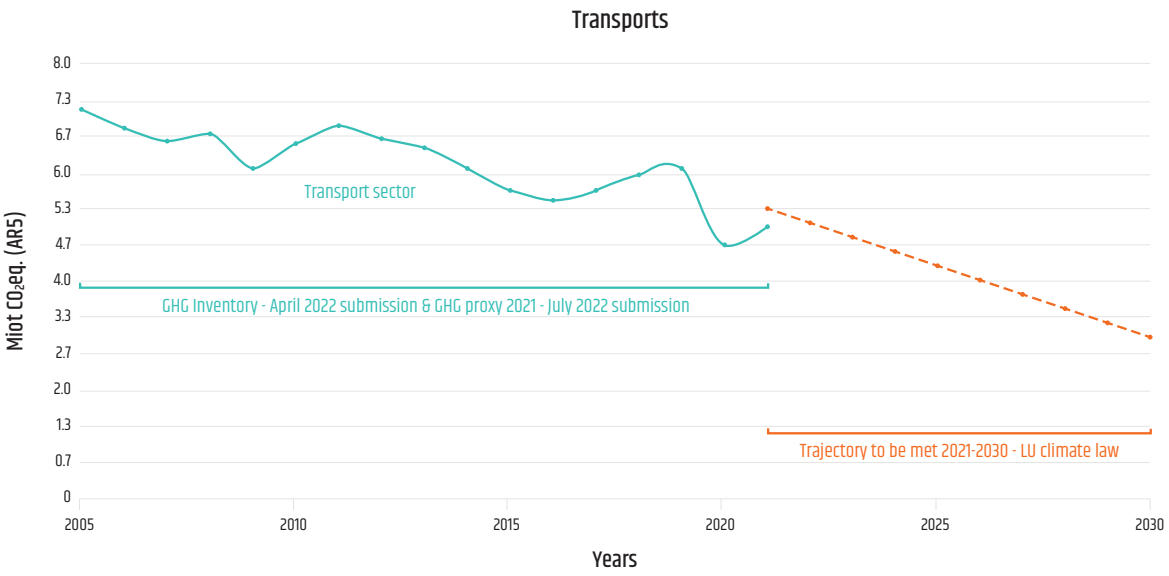
In the case of existing buildings, the situation is less clear. There is no strict regulation on the energy performance as in the case for new buildings. The renovation of existing buildings and the replacement of fossil fuelled heating systems by carbon neutral alternatives mostly depends on the house owner. For house owners that live in their own homes, the incentives to renovate are relatively high due to the subsidy programmes, CO_2-tax, and increasing energy prices. In contrast, for rented houses and apartments, the incentives to invest in renovation and carbon free heating system are lower because the investment decision lies with the house owner, whereas the renter pays the energy and CO_2-cost. There is one instrument that would address these problems and speed up the green transition in the buildings sector:

- **Ban fossil heating systems**: For example, the regulation for new buildings (see above) should also be implemented for existing buildings. It needs to apply whenever a heating system has to be replaced. Of course, this policy needs to be complemented with hardship rule in cases the replacement is not possible and financial support for households that cannot afford it.

4.2. Transport/Mobility

4.2.1 Past emissions and reduction targets

Figure 4.2: Emissions from transport and trajectory to be met according to Luxembourg's climate law.



Notes: The transport sector represented in this figure is composed of emissions from domestic aviation (negligible in Luxembourg), road transport, railways (low in Luxembourg as all the network is electrified) and inland navigation (negligible in Luxembourg): these emissions are those that count for Luxembourg's national and international commitments. There is also international aviation, which is not pictured in the figure as it is excluded from international commitments as are all international bunkers (aviation & shipping). The figures from 2005 to 2021 (2021 still provisional) are calculations of GHG emissions from GHG inventories prepared according to IPCC guidelines and submitted annually to the UNFCCC and the European Commission. The blue dotted line represents the sectoral target for the transport sector (excl. International aviation) according to the Luxembourg climate law. Values are expressed in millions of tonnes of CO_2eq. based on IPCC 100-year global warming potentials (GWP100) from the 5th Assessment Report.

Figure 4.2 shows the historic emissions as well as the future emission targets for the Luxembourgish transport sector. It shows that in the past 15 years, emissions in the transport sector decreased, reaching a level of 4.9 Mt CO_2eq. in 2021. This is below the target of 5.3 Mt CO_2eq. However, 2020 and 2021 levels were strongly influenced by the Covid-19 pandemic. Comparing the slope of the emission trajectory from the past with the target path for the future, it is clear that substantial additional policy measures will be needed.

Greenhouse gas emissions from the transport sector in Luxembourg come predominantly from the high volume of road traffic, but the aviation sector also contributes. Between 2000 and 2020, emissions from aviation rose from 1.3 to 1.7 million tonnes of CO_2eq. Between 2000 and 2021, emissions from road transport fell from 7.2 to 4.9 million tonnes of CO_2eq. (6.2 million tonnes of CO_2eq. in 2019 before the Covid-19 pandemic): see figure 4.2. In 2021, this amounted to 53% of Luxembourg's overall GHG emissions, excl. international aviation and Land Use, Land-Use Change and Forestry (LULUCF). Road transportation includes freight transport (heavy-duty vehicles), vans, buses, and private cars. Reducing GHG emissions from the transport sector is urgent and key to responding to the climate challenge and to meet Luxembourg's goal of climate neutrality. The aviation sector is an important sector for transport overall, but this will be covered in the next report(s) in further detail.

Road vehicles, and especially private automobiles, claim space, time, and energy, pollute clean air, produce noise, and hence negatively affect well-being, to deliver a mobility service with very low efficiency from a collective perspective. Air pollution is the biggest environmental health risk in Europe, with the European Environment Agency (EEA) reporting that in 2019, 307,000 people died prematurely in the EU as a result of air pollutants[55]. A recent report by the International Energy Agency (IEA) identifies SUVs as the second most important driver of the emissions increase between 2010 and 2018 [56]. In Luxembourg, the number of cars per inhabitants is still increasing, even though it already represents the highest share in the EU, and private vehicles become still heavier and emit more carbon[57]. Automobiles remain a reasonable option for many mobility needs and are still today a status symbol for the highest-income segment of society.

4.2.2 Need for transformation

Transforming the mobility system and the transport sector requires policies that will need to work as both carrots and sticks. These policies include structural changes in the transport sector, and measures to change behaviour and incentivise more sustainable transport or mobility habits[58].

The following transformations are needed to drastically reduce GHG emissions in Luxembourg's transport sector:

Sufficiency

The vision of sufficiency in the transport sector requires choices and policies to reduce the need for physical mobility in the first place. Not moving means not emitting the emissions associated with transport. Such measures could include:

- **Land use and urban planning to reduce space for cars**, either on roads or for parking: A very clear signal would be to ban the building of new roads as has been done by the Welsh government[59].
- **Developing plans for a 15-minute city**, where amenities and necessities are within a 15 minute walk or bicycle ride from residencies.
- **Promoting working from home** instead of travel to workplaces.

Efficiency

An efficiency framing of transformation in the mobility system requires policies to shift the transport needs to sustainable modes of transport as much as possible. Measures could include:

- **Incentivise the modal shift from a car-centric to a shared, soft mobility system**: Shift to an integrated system connecting (renewable) public transport, bicycle infrastructure, safe infrastructure for pedestrians. Literature suggests that shifting away from cars can be accomplished by communicating about the positive sides of alternatives, as was done in Copenhagen, whose successful cycling communication never mentioned cars or climate change[60].
- **Spatial planning** efforts to make it easier to benefit from the excellent initiative to provide free public transport, e.g., by making it easier for bicycles and pedestrians to connect to and use the public transport infrastructure and by making it more difficult for the private car to remain a central mode of transport, by, e.g.:
    a. Expanding the public transport offer;
    b. Connecting to bicycle parking (bike and ride);
    c. Building more protected bicycle lanes and develop more pedestrian zones;
    d. Reducing speed limits to limit emissions, increase safety and reduce the time-incentive for car travel;
    e. Implementing low emission zones and traffic calming infrastructure or increasing car-free zones.

Renewable Energy

The remaining fleet of passenger vehicles must be progressively decarbonised:

- **Increase share of electric vehicles (EV) and ban of fossil fuel vehicles**: The ban of the sale of fossil fuel cars in the EU is planned for 2035. Luxembourg could advance the ban by 5-10 years. As complementary measure, the subsidy for EV could be continued and adjusted at a lower amount if necessary. The subsidy should be conditional on the subscription of an electricity contract supporting the increase of local renewable energy capacity to unlock the full decarbonisation potential of EV.

4.3. Energy Systems

The energy networks are closely linked to the buildings and transport sectors, as primary users of energy, and their sufficiency measures. The linkage is expected to become stronger in the future as decarbonisation of building and mobility will heavily rely on electrification. As a result, increasing the generation of cleaner electricity and thereby reducing the dependency on imports from foreign markets is a key strategic move that should be carefully considered and planned. To this aim, priority should be given to the increase of local capacity of cleaner electricity production, mainly from renewables, and to direct investments into capacity of renewable generation abroad. Currently, in the European market, energy certificates (certificates of origin) are a widely accepted instrument to virtually allocate renewable electricity production to national accounts. However, there is evidence that, since their inception, those certificates have failed to contribute to increase renewable energy production capacity (which was the purpose they were created for) and that double-counting and flawed allocations in accounting systems happened[61]. As such evidence is likely to become stronger in the future, it is recommended not to rely on these certificates, but instead, it is recommended to directly invest in building renewable energy production capacity, which can consistently allocated to national accounts.

- **Increase the generation of renewable energy production and thereby decrease the dependency on imports from foreign markets**. Priority should be given to the increase of local capacity of clean electricity production, mainly from renewables, and to direct investments into capacity of renewable generation abroad. It is recommended not to rely on energy certificates (certificates of origin), but instead, directly invest in building renewable energy production capacity both on the national territory and abroad, which can consistently allocated to national accounts.

Efficiency

- **Continue and strengthen the measures in place to reach aiming for a reduction of final energy** demand of between 40% and 44% by 2030 compared to the EU PRIMES[62] baseline. In addition, efforts put into place to reduce gas consumption this winter by 15% compared to the reference period 2017-2021 as highlighted by the campaign "Zesummen spueren, zesummenhaalen" should be continued after the energy crisis.

Renewable energy

Increasing the share of renewable power. A share of 50–70% of domestic electricity self-generation from renewable energy (RE) sources in Luxembourg is foreseen by the year 2050 (Creos 2020), following a 25% share in 2030 according to the PNEC. Luxembourg is also accelerating the deployment of small-scale photovoltaics[63]. A range of incentives will be deployed according to the PNEC to increase both small-scale and large-scale renewable energy production.

The capacity of renewable energy production should be systematically increased, in combination with other types of land use in order not to increase the pressure on land and/or generate competition between land uses. Examples are the use of rooftop solar panels or the use of panels over agricultural production fields. A smart combination of small-scale capacity very close to demand sources and mid-size power units, e.g., for residential areas or larger activity zones, are a good compromise between minimisation of transmission losses and good production efficiency. An important drawback of increasing the renewables capacity lies in their intermittency. To ensure energy availability with variable renewable energy sources, main solutions to promote are storage, demand-side-management, and load time shift as well as dynamic tariffs (whereby price follows renewable energy generation or low-carbon content of electricity). EV batteries can effectively contribute to curtailing power peaks. With a demand-side power control capability, an EV is able to delay the charging sequence from day to night. Legal terms should then be clarified for certifications and authorisations, as well as for the definition of the vehicle-to-grid standard, and its impacts on the prices for the end customer/prosumer.

- **Increasing the share of renewable power** (e.g., rooftop solar panels or the use of panels over agricultural production fields). Favour the combination small-scale capacity in proximity to demand sources and mid-size power units for optimal trade-off between transmission losses and good production efficiency.

The war in Ukraine and the current energy crisis

Recent geopolitical upheavals have exacerbated the energy situation in Luxembourg and the EU. Russia's war on Ukraine has severely reduced the supply of previously cheap gas to European countries, resulting in an energy crisis that affects households as well as industrial and agricultural production. It is important to note that the energy crisis began in late 2021, well before the Russian invasion, but was dramatically and rapidly aggravated by the invasion.

In addition to limited gas supply and very high gas prices, electricity markets are suffering from low nuclear production in France due to inspections and repairs and low hydroelectric production in many European countries due to low water levels following droughts. As a result, gas prices, but also electricity prices, have soared, and Europe is bracing for power shortages this winter.

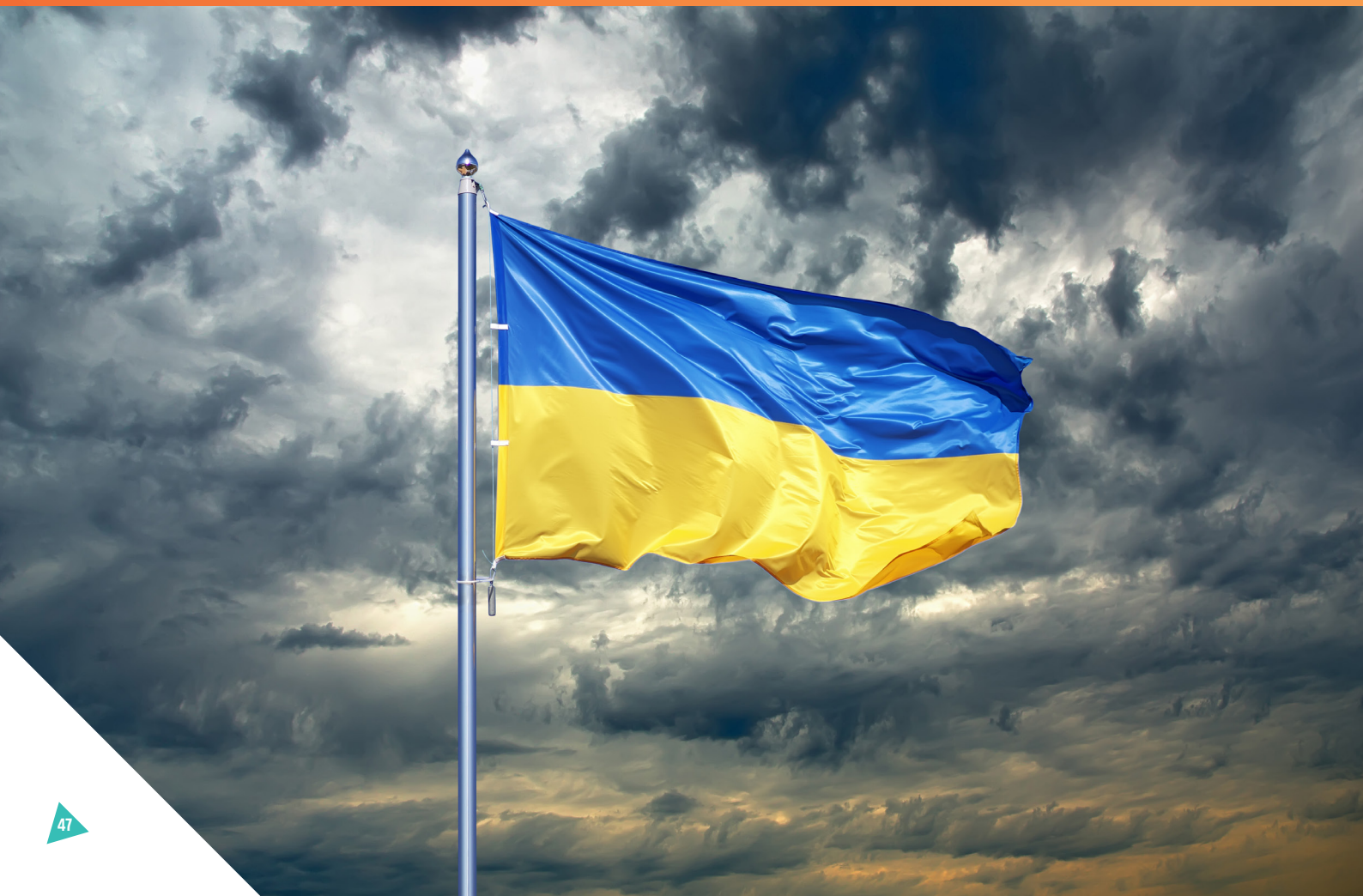
These developments have led to two types of measures in Luxembourg and throughout Europe:

First, financial support for households and companies: An immediate measure taken in Luxembourg included the allocation of a subsidy on petrol between April and August 2022, a controversial measure that directly counteracts the CO_2 tax. In addition, in March 2022, the Luxembourg government also introduced an "energy tax credit" for lower income households to compensate for rising energy prices[64].

Second, the gas and electricity saving programmes: At the time of writing, the most prominent programme is the voluntary energy saving campaign "Zesummen spueren, zesummenhaalen", which aims to reduce gas consumption this winter by 15% compared to the reference period 2017-2021 [65].

Against this background, the OPC makes two recommendations:

- **Financial support for vulnerable households and companies**: In times of inflation and high energy prices, financial support for vulnerable households and companies is important. Such support must reach precisely those who need it most.
- **No subsidies to fossil energy**: General subsidies to fossil fuels must be avoided at all times, as these directly counteract the CO_2 tax.



4.4. Food, Agriculture and Forestry

As specified in Section 2.13, Luxembourg's Climate Law (2020) establishes a framework for a safe and healthy climate for humans and biodiversity, while continuing action to limit the rise in global average temperature to 1.5 °C above pre-industrial levels. In order to achieve this, it sets an economy wide mitigation target of 55% emission reductions by 2030 compared to 2005 and reaching "net zero emissions" in Luxembourg in 2050 at the latest. The Grand-Ducal regulation of 22 June 2022 allocates a reduction of 30% of emissions by 2030 compared to 2005 to the agriculture and forestry sector, but the land sector will have an important role to play in reaching "net-zero emissions".

In terms of a Just Transition towards a sustainable society and the deep decarbonisation required to meet these goals, the management of land-use climate interactions in agriculture and forestry has several important roles to play (policies on urban and spatial planning are beyond the scope of this first report but will be addressed in further work of the OPC). This chapter on the topic of land-climate interactions addresses climate change mitigation in terms of emissions reduction and increasing carbon sequestration in woody structures and soil across the entire territory where possible. Adaptation to climate change, on the other hand, warrants both changes in land use and land management to ensure that ecosystems (whether productive or for conservation) will become more resilient to changing weather patterns and extreme weather events. This is for the sake of the intrinsic value of diverse forms of life as we know them, as well as for securing the provision of ecosystem services that humans depend on for their existence and flourishing. The chapter is organised in view of goals relating to sufficiency, efficiency, and carbon sequestration.

Setting sufficiency goals invites to reframe human demands to what is essential and adequate in order to align better with the biophysical carrying capacity of the territory. A profound adaptation is required in individual and societal demands, looking at the types, quality, and quantity of agricultural and forestry products that are purchased and used (wood is mainly used in construction or energy conversion and will be treated there). Actual changes in demand are already becoming apparent in some segments of the population. Actual goals and associated strategies to align demand better to the biophysical capacity of the Luxembourg territory will also have profound implications for land used for food production and in particular the types of food and fibre crops that are cultivated. A first summary of selected future-oriented studies on potentials for Luxembourg is discussed in this report, future work of the OPC will take up these topics exploring new angles in more detail.

Efficiency goals in this sector are set to reduce waste in the form of harmful emissions and unused by-products, and to minimise inputs in production. **This set of goals** first directs our attention to the reduction of GHG emissions from land management practices in agriculture in particular. **The second concern** is minimising our dependency on production-related inputs including chemical pesticides and fertilisers that in themselves are energy-intensive to produce and the supply of which is becoming increasingly uncertain. **The third production-related concern** is becoming more efficient in extracting valuable resources from to date unused by-products, such as looking at unused manure as a source of nutrients such as phosphate and closing other material flow loops in the logic of the circular economy. On the demand side, the main efficiency challenge is the reduction of food waste to an absolute minimum; this will require profound and disruptive social innovations in the value chain and access to foods in particular by more vulnerable groups in society.

On carbon sequestration: Successful changes in pursuit of the above goals depend upon the proactive human fostering of the self-regenerative capacity of ecosystems (aquatic and terrestrial, more or less managed) to enhance their resilience to climate change impacts. The regeneration of healthy ecosystems in and above the soil is a prerequisite for targeting and promoting the capacity of storing more carbon from the atmosphere. **It is Luxembourg's only chance for meeting the ambitious goal of the climate law for making Luxembourg a carbon neutral territory 2050 at the latest**. Moreover, well-being and quality of life, or in the words of the law, human flourishing in a 'healthy climate', depends on a wide range of ecosystem services that have already been jeopardised by the increasing frequency of extreme weather events including recurrent strong heat waves and summer droughts over the last 60 years, with more pronounced impacts since at least 2018.

Accordingly, this chapter will first determine selection of main relevant facets of the current situation relating to land use and management with a focus on forests and agricultural land in Luxembourg, before setting out recommendations of a first selection of recommended measures relating to goals of sufficiency, efficiency and the self-regenerative capacity of ecosystems. The conclusions and outlook will include considerations relating to governance, the co-creation of evidence for policies, and finance to achieve the recommended measures in a way that takes social justice as a central concern.

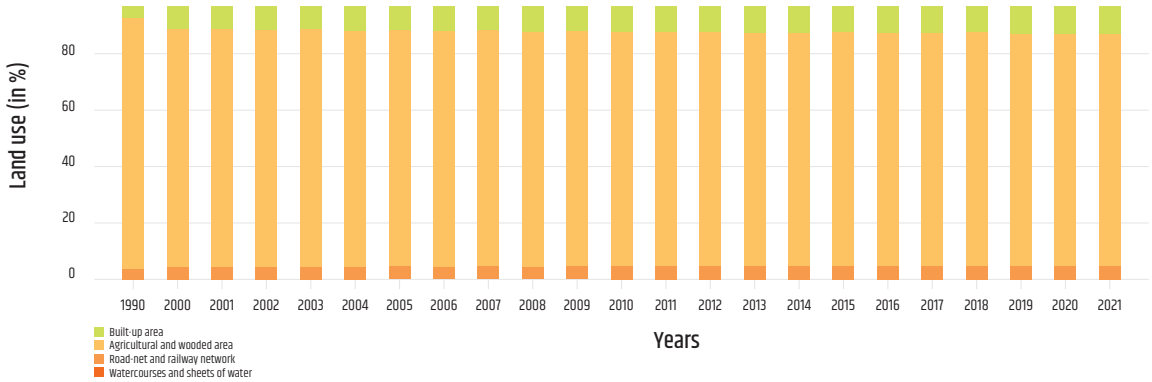
4.4.1 Biophysical facts on land use and management

Luxembourg has a total area of 2,586 km² that is divided into two natural areas: the North with the Oesling (Eisléck) of 828 km² and the South with the Good Country (Guttland) of 1,758 km². The longest distance from North to South is 82 km, and the largest distance from East to West is 57 km. This report will focus on the agricultural areas with 1,286 km² that make up just about half – 50% – of the country surface, and forests, that are just under 1,000 km² and make up close to 35% of the country's surface area.

Developments over the last 30 years demonstrate a fairly steady net land take rate of about 0.5 ha per day on average (see Figure 4.3). Whilst sealed settlement surfaces nearly doubled from about 6% in 1990 to just under 12% in 2020, and transport takes up 3.7% of the country land area, impacts of current policies and practice in these areas on land-climate interactions are not considered in further detail in this report other than in the sections on housing and mobility policies. It is however strongly recommended that policies are put in place to prevent further conversion of forested areas and nature protection zones to settlements. Furthermore, recommendations to increase the number of trees and green spaces and care of soil in all urban and peri-urban areas are highlighted. Any further consideration of spatial and urban planning is beyond the scope of this first report.

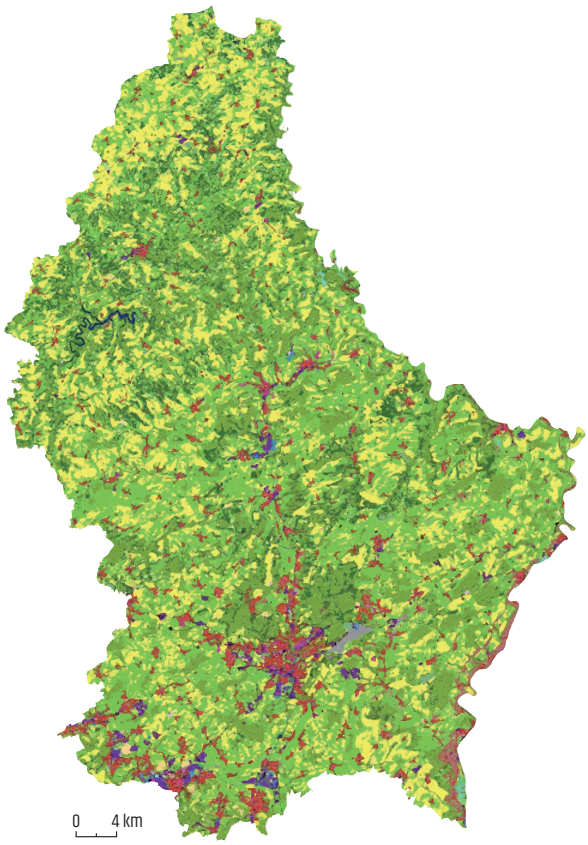
- **Reduce net land take from about 0.5 ha per day to 0 ha per year**: by reducing the sealing of new surfaces for settlements, economic activities, or transport to zero or compensate by unsealing surfaces for newly sealed surfaces.

Figure 4.3: STATEC Figure on Land use from 1990 to 2021



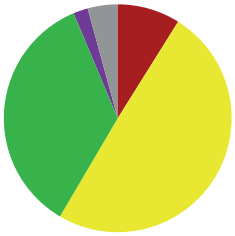
Source: STATEC [66]

Figure 4.4: Land use map 2020



Land Use 2018 classes

- Settlement · residential
- Settlement · agricultural facility
- Settlement · industry and commerce
- Settlement · unused urban areas and brownfields
- Settlement · social, military, cultural and other infrastructures
- Settlement · public facilities · cemetery
- Settlement · public facilities · square
- Settlement · public facilities · park
- Settlement · public facilities · other
- Settlement · sport and leisure · golf course
- Settlement · sport and leisure · camp ground
- Settlement · sport and leisure · other sports facilites
- Settlement · sport and leisure · other recreation facilites
- Settlement · technical infrastructure · utility (production and disposa facilities)
- Settlement · technical infrastructure · mining and extraction
- Settlement · construction
- Agriculture · arable land
- Agriculture · grassland
- Agriculture · special culture · vineyards
- Agriculture · special culture · fruit trees
- Agriculture · special culture · orchard
- Agriculture · special culture · other
- Forest block · coniferous
- Forest block · mixed
- Forest block · deciduous
- Forest block · young forest
- Forest · clearing · burnt area
- Forest · clearing · clear cut
- Natural surface · gravel
- Natural surface · rocks
- Natural surface · grassland
- Natural surface · heathland
- Natural surface · bushes
- Natural surface · wetland
- Water · running water · natural
- Water · running water · artificial
- Water · standing water · natural
- Water · standing water · artificial
- Transport · road · rural
- Transport · road · main
- Transport · railway
- Transport · air traffic · commercial
- Transport · air traffic · sport and leisure
- Transport · water traffic
- Transport · parking



LU 2018 class	Area (km²)	Area (%)
Settlement	226.2	8.7
Agriculture	1286.0	49.6
Forest	924.3	35.6
Nat. surf.	48.2	1.9
Water	11.6	0.4
Transport	96.7	3.7
SUM	2593.1	100.0

Note: An approach based on aerial images, LiDAR and ancillary GIS data; Report Space4Environment. Developed with open data from 2018.

4.4.2 Transformation needs

Sufficiency

The IPCC WGII report recognises demand-side mitigation options as an important way of reducing GHG emissions in end-use sectors. For land related emissions, a shift away from GHG-intensive diets, in particular meat-based diets, towards balanced, sustainable healthy diets[67] is identified as one of the measures with strongest reduction potential:

- **Shift to balanced, sustainable healthy diets**: A profound adaptation is required in individual and societal demands, looking at the types, quality, and quantity of agricultural products that are purchased and used. A shift towards more plant-based diets would not only promise health benefits compared to consuming high levels of red meat, but additionally help to reduce the demand side option of reduced livestock in Luxembourg. Strategies to better align demand to the biophysical capacity of the Luxembourgish territory will also have profound implications for land use for food and fibre production. An awareness-raising campaign on the relation between dietary and climate change and attention to affordability of regional, seasonal, and organically grown foods could be a first step in this direction.

Efficiency

Another demand-side measure includes the continuation and acceleration of the promotion of concepts behind the current "Anti gaspi" campaign[68], to reduce food waste to minimum by consumers. In addition, one needs to raise awareness in the agricultural and gastronomy sector to reduce food loss.

Stepping up the existing "anti-gaspi" campaign: In addition, efficiency from farm to fork urgently requires reducing food waste in households, food service and along the supply chain[69]. It has been estimated that food waste accounts for 25% of food related GHG emissions in Luxembourg.

- **Reduce food loss and food waste**: Continue and accelerate the promotion of concepts behind the current "Anti gaspi" campaign, to reduce the food waste to minimum by consumers. In addition, raise awareness in the agricultural and gastronomy sector to reduce food lost. This will require profound and disruptive social innovations in the value chain and access to foods in particular by more vulnerable groups in society.

The Luxembourgish national inventory[70] highlights that all sectors covered reduced their greenhouse gas emissions (GHG) between 1990 and 2020, except for agriculture, where emissions decreased until 2006 but increased back to nearly 1990 levels in 2020, mainly due to an increase in livestock. In 2020, it represented the second largest emission sector after energy.

Direct, biogenic agricultural emissions can only be addressed by changing agricultural production systems, such as reducing methane generated by ruminant livestock through feed additives, reducing tillage, avoiding over-application of fertiliser to reduce the N_2O emissions, or by changing diets to shift away from livestock with larger GHG emissions per gram of protein. Fossil fuels also play a role in food production, from direct combustion by agricultural machinery or in the production of synthetic fertilisers, pesticides and packaging, food processing, and distribution. Decarbonisation in electricity production and in transportation will also reduce supply chain emissions in food production.

There is increasing readiness within the Ministry of Agriculture, Viticulture and Rural Development[71] to reduce livestock numbers. This is in some cases, however, difficult due to investments in stables or milking robots that need to be paid back. Given the links between cattle, manure and fertiliser, considerations of policies on fertilisers and pesticides are of direct relevance to land climate interactions. Measures to decrease the dependency on fossil fuels and reduce fossil fuel inputs in agricultural production are also required:

- **Reduce methane and nitrous oxide emissions in agriculture**: For Luxembourg 70-80% of methane emissions and nearly all nitrous oxide emissions are caused by agricultural activities. Measures aiming at reducing the livestock size in Luxembourg would lower the methane emissions, while the reduced use of fertilisers would reduce the nitrous oxide emissions.

Taking a life cycle perspective, reducing reliance on energy-intensive production means (including chemical fertilisers and pesticides) also needs to be considered as part of measures to reduce production emissions in agriculture. These considerations are in line with the targets on a 50% reduction in the use of pesticides by 2030 and up to 20% reduced use of fertiliser. For pesticides the trend is compared to a three-year baseline, comprising the average use in the years of 2015, 2016 and 2017 for each country[72]. For fertilisers, the baseline comparison is the average gross balance of nitrogen applied to each ha of agricultural land between 2012-2014. The profile of Luxembourg's agriculture industry in terms of key performance indicators collected by EUROSTAT (based on 2018 or earlier data) has three outliers: the relatively very high use of chemical pesticides per area of agricultural land; the high inputs of nitrogen and the lack of structural elements in agricultural landscapes (COM(2020) 846 final). These issues are addressed in the new strategy the Ministry of Agriculture submitted on 31.12.2021 after a public consultation:

- **Minimize dependency on production-related inputs**, including chemical pesticides and fertilisers and fossil fuels, that in themselves are energy-intensive to produce and the supply of which is becoming increasingly uncertain. More targeted measures to reduce dependency on chemical fertilisers and pesticides are needed with more targeted promotion of their replacement with nature-based solutions such as those used in integrated pest management and modern agroforestry systems. Experimentation with different NBS in test beds should be actively encouraged and supported. More stringent standards for judicial use of chemical pesticides and fertilisers should be set for conventional farmers.
- **Increase efficiency in extracting valuable resources** from to date unused by-products, such as looking at unused manure as a source of nutrients such as phosphate and closing other material flow loops in the logic of the circular economy.

Promoting carbon sequestration and self-regeneration capacity of ecosystems

Luxembourgish climate law stipulates that "net zero emissions" in Luxembourg must be reached in 2050 at the latest. Mitigating climate change does not only depend on the strategies to reduce GHG emissions embodied in the goods and services we consume, but also on the capacity of ecosystems to capture CO_2. Forests, and to a lesser extent grasslands, are those ecosystems where carbon sequestration flows may increase on a yearly basis, while croplands, wetlands and other natural or semi-natural ecosystem types either marginally contribute to increased carbon sequestration rates or provide a zero balance between carbon storage and release. Moreover, efforts to increase green areas in cities and include nature-based solutions in built-up land can be put in place to increase the global climate regulation service.

While the LULUCF sector in Luxembourg has been a net sink since 1991, it was in 1999 that a maximum of 6.6% of the national emissions were removed, and this figure has fallen to around 3% in recent years. STATEC Data shows that agricultural and woody area in Luxembourg decreased from 91.8% in 1990 to 84.6% in 2021, mainly due to an increase in built-up areas, which have more than doubled (4.3% to 10.2%). On the basis on these main trends and drivers it is clear that Luxembourg will not be able to meet the target as fixed in the national climate law of being climate neutral in 2050 at the latest, if emissions in all sectors, including agriculture are not drastically reduced and removals in the LULUCF sector are strongly increased.

Forestry: Prevent deforestation, foster afforestation, that subsidises private forest owners to replant areas that have been damaged. Policies already exist to promote these measures which should help the national forest to move away from monocultures, help to reduce their vulnerability to the impacts of climate change, and increase biodiversity as well as carbon sequestration. these practices should be extended to private forest owners, but it is however notably difficult to reach them. Challenges here lie in implementation and creativity.

- **Promote carbon sequestration in healthy and resilient forests**: **Reduced conversion of forests and afforestation, reforestation**: The main driver here in Luxembourg is the conversion of forest and agricultural land to built-up areas. This is an important driver to slow down and stop sealing of land surfaces in order to keep the maximum of land surface that can contribute to carbon sequestration. **Improved sustainable forest management**: This measure should help the national forest to move away from monocultures, which would help to reduce their vulnerability to the impacts of climate change, increase biodiversity as well as carbon sequestration. **Improve approaches to reach and engage private forest owners**: Explore potential to restore built-up areas in Luxembourg to forested areas.

Reduced conversion of forests and afforestation, reforestation: In relation to climate change, the daily rate of net land take has been around 0.5 ha / day over the last decade. The conversion of forests and agricultural land to built-up areas is therefore significant, but laws are being passed to curb these developments. This will be subject of a future OPC report. An important policy goal for climate change mitigation is to keep the maximum of land surface that can contribute to carbon sequestration. The potential to restore built-up areas in Luxembourg to forested areas should be explored.

- **Reduce net land take from about 0.5 ha per day to 0 ha per year**: by reducing the sealing of new surfaces for settlements, economic activities, or transport to zero or compensate by unsealing surfaces for newly sealed surfaces.

Planting new trees for adaptation and mitigation and resilient ecosystems: The Luxembourgish government is preparing to implement measures to ensure a suitable Luxembourgish contribution to the EU target of planting 3 billion new trees by 2030, which translates to 1.7 million trees, which withstand climate change in Luxembourg. This will help to inverse the current trend of loss of forested and agricultural land by built-up land. Legal underpinning of this measure should promote planting of trees where there have been trees before as well as land were there have been none before, including on agricultural land and urban areas, but at the same time exempt the areas that those newly trees stand on from restrictions relating to forests or nature protection zones or habitats of protected species.

Carbon sequestration in soil: Potential carbon (C) sequestration in the soils of the grassland and forage areas exists by means of but not excluded to nitrogen-fixing mixtures of grass, clover and fodder legumes. The ambitious goal of responsible agricultural policy must be the promotion of soil life par excellence. Living soils allow better rooting of the crops grown. Deep-rooted soils have a higher water absorption capacity - more rainwater remains in the soil. The increased aeration allows aerobic decomposition of plant residues (less methane emissions) and of the added organic fertilisers (less nitrous oxide emissions). The total biomass in the soil, consisting of roots, organic fertiliser, worms, bacteria, rhizomes, viruses, and fungi, can bind/fix carbon (C) up to a level of 10 t CO_2eq. per ha.

Excellent provisions to promote care for soil and humus formation that enriches soils with carbon in agricultural policies:

- **Promote carbon sequestration on agricultural land in woody structures and soil**: In order to strongly increase carbon sequestration in agriculture in Luxembourg, targeted measures and monitoring of humus content and soil life and its remuneration as an ecosystem service is necessary, on and beyond farmland. Furthermore, to promote more woody structures on farmland, agroforestry potential should be explored and promoted. Agroforestry is not only of interest to increase carbon sequestration but also to help the agricultural sector to adapt to climate change, all the while helping to address biodiversity loss and promote local fruit production.

Ecosystem regeneration and fostering the self-regenrative and adapative capacity of ecosystems

Adaptation to climate change by diverse ecosystems in Luxembourg will require them to self-regeneration after impacts of extreme weather events as well as organisms in different ecosystems adapting to changing weather patterns. This holds true for managed and unmanaged ecosystems alike. The resilience of ecosystems against climate change is largely determined by their biodiversity and of their interconnectedness with adjacent other differentiated ecosystems. They make species migrations permissible as environmental conditions change and shift with altering weather patterns. Planning ecosystem regeneration across the level of the landscape and linking up strategies across forests, farmlands, and protected zones will prove to be crucial. The capacity of an ecosystem to perform certain functions is directly dependent on its health. In turn, directly impacts its resilience to changing conditions. Such pivotal ecosystem functions include improved water management and water retention of soil. They make a difference to impacts of extreme weather events including drought and heat stress but also extreme rainfall. Plant cover ensures limited evapotranspiration, which makes for a more favourable microclimate from increased air moisture and the cooling effect of the evaporation process. Nutrient cycling and making nutrients available for plant growth, including nitrogen fixation from the atmosphere, is a function from soil microbes. Carbon sequestration takes place in woody structures above soil as well as in soil through humus formation itself. Pollinators play a crucial role in allowing the development of fruiting bodies in many plant species including most of our fruit and vegetables.

Maintaining all these services in ecosystems will require not only the reduction of harmful substances in the environment, including pesticides and elevated levels of nutrients from over-fertilisation, but also dedicated regenerative activities to ensure connectedness of diverse habitats and an increase in structures to provide shelter for diverse species. In relation to the EU 2030 target to have 10% of agricultural land with a high diversity of landscape features, Luxembourg has the lowest proportion with structural elements compared to other EU countries based on the 2015 LUCAS survey[73] conducted by EUROSTAT (well below the EU reference value of 4.6%).

The conservation status of natural diverse habitats and species in Luxembourg is now alarming[74]. Two thirds of the natural habitats are in an "inadequate" or "poor" conservation status. Only one third can still be said to be in a "favourable" condition. In addition, soils on EU agricultural land have generally deteriorated; EU and Luxembourg water resources were, during the three subsequent droughts in 2018-2020, severely stressed and have increasingly deteriorated in condition.

Resilient food production systems: Longer and more diverse crop rotations, richer crops with more diversified plant species, intercropping, under sowing, direct seeding and reducing (deep) ploughing in order to disturb or endanger the soil fauna and flora less often and deeply, must become common agricultural practices. Grasslands that are used by cattle, sheep, or goats (mowing, grazing, etc.) only need a part of the excrements of the animals they have nourished/carried to compensate for the loss/export via the nutrients contained in the milk, meat, and nutriments:

- **Promote ecosystem restoration, and planting trees in urbanised areas** can help make cities more resilient to impacts of extreme weather events. Within settlements, the maintenance or creation of green spaces and planting of trees can increase the carbon sequestration and also help to reduce local temperatures and thus help to adapt settlements to climate change.

5 Outlook and further research

In this first climate report for Luxembourg, the OPC has set the scene regarding Luxembourg's climate change situation and conditions. This included identifying which EU and supra-national policies determine political action in Luxembourg with regard to GHG emissions reduction and development of other climate-relevant factors, as well as mapping the situation for some of Luxembourg's key industries and their integration into the international context.

In doing so, the report drew on EU and other international documents, national reports, and analyses, as well as policy roadmaps that determine (some of) the main areas of contention in the EU and Luxembourg. Most importantly, these resources establish the ***key principles*** according to which the OPC has and will assess climate change mitigation (and potentially adaptation) *developments, policies, and projects in Luxembourg*, will examine examples of benchmarks from other contexts and countries, and will provide scientifically sound in-depth studies in the future.

The report was developed in parallel, but independently of the concrete citizen participation in Luxembourg (*Klima-Biergerrot*[75]) and is further informed by ideas pertaining to citizens' assembly and governance. In this spirit, the report presents a collection of thoughts in the line of transformative governance through the inclusion of citizen councils and citizen science.

Figure 1.1 marks the starting point of the report. The report is structured in view of goals relating to sufficiency, efficiency, renewable energy, and carbon sequestration. They form the key principles through which we analyse Luxembourg's "transformation to a sustainable and decarbonised society", and which will guide the OPC's future work.

The report focuses on selected key controversial issues/areas of contention – including buildings/housing, transport/mobility, electricity/power sector, food, agriculture and forestry – which are not only important for Luxembourg's economic development and GDP but are also important drivers of carbonisation and climate-change. Building on our first stocktaking, we identified Luxembourg as a – so called – 'climate policy lab', in which current and new approaches to governance were examined, including accountability of the government to its citizens and of the industry to society. Furthermore, the report highlights gaps and interesting avenues for research that will inform our analysis and analytical angles for the future. Below, we present a mere collection of ideas distilled from this report, which in itself formulates an ambitious research agenda, and on which the OPC will follow up selectively.

Examples of topics for further research projects include ways/processes from just transition to just transformation; means and measures of 'just resilience' for key industry sectors in Luxembourg; what a sustainable future of agriculture in Luxembourg would look like; ways that processes of integrating mitigation and adaptation policies could be fruitfully blended with policy integration and coherence in Luxembourg and the Greater Region (and beyond); and Luxembourg's role in setting but also being held accountable to meet and further develop the sustainability agenda at the EU level. More specifically, we have identified four rather concrete areas of contention for further research and guidance in policy making:

1. **Implementation of EU emission trading for buildings and road transport**: In the coming years, EU emission trading for the buildings and road transport sectors will be implemented. This implies an additional price on carbon emissions from road transport and buildings. The sectoral scope of this new price will have significant overlap with the existing national CO_2-tax. Thus, Luxembourg (like many countries with national CO_2-taxes) will need to work out whether and how to combine the existing national CO_2-tax with the new emission trading system. This includes technical questions (scope, accounting, etc.) as well as political questions (level of national tax, use of revenues etc.). For the latter, the OPC could provide guidance on the impacts of different options.

2. **Luxembourg as a climate policy lab**: Given its small size, good organisation, and partly high data availability (e.g., smart meters), Luxembourg is well suited to observe and evaluate impacts of policy measures on the whole population. In other words, the country can serve as a climate policy lab to test or accompany individual policy measures, or the green transition in general. To this end, data needs to be collected and made available in an easily accessible and transparent way, which is only partially the case so far, and suitable policy evaluation methods need to be applied to get meaningful results from the data. The OPC could provide guidance in developing and implementing (smaller or larger) policy evaluation projects, as well as research into Luxembourg as living policy and practice lab for the Just Transformation and decarbonisation of, for example, land use, individual travel behaviour and lifestyles, and food production.

3. **Monitoring the socio-economic impacts of sustainable transition and energy crisis**: The current situation with a mix of climate policy measures and high energy prices has substantial implications for households and companies. For example, vulnerable households might be excessively burdened by high prices and new regulation; or companies need to transform their business model due to the green transition, implying new requirements for training and education of employees. Such socio-economic impacts need to be observed and – where necessary – addressed. The OPC could provide guidance in developing a suitable monitoring system.

4. **(Private) finance as an enabler in unlocking climate change mitigation strategies**: Parts of the financial industry have evolved into a growth industry in its own right. Some legal-financial (mal) structures and instruments facilitate and foster process of financialisation, thereby countering processes of just transformation/transition towards sustainable and decarbonised societies. However, the emerging opportunities for sustainable finance may strengthen the profile of Luxembourg's IFC as a truly sustainable finance hub. Emerging issues for the future may include, how democratic principles can be better mirrored in financial institutions and markets; how and where rationale for alternative/post-growth economies could be linked with opportunities provided by sustainable finance and digitalisation, or the role of Luxembourg's microfinance sector to cushion and mitigate profound social implications from the multiple (energy, health, economic, etc.) crises.

This first report has been an opportunity to lay the foundations on major achievements in Luxembourg's climate policy. Importantly, the OPC agrees that the government of the Grand Duchy of Luxembourg is well aware of (most of) the pressing issues and has already adopted a range of policy measures to mitigate climate change and reduce GHG emissions. However, more can and must be done.

Luxembourg, however, cannot embark on this journey alone; its geographic location and deep structural entwinement with neighbouring countries, as well as the EU single market, require concerted effort to (re)design regional supply chains and (re)build stronger, more regionally-oriented economies. Luxembourg's municipalities play an important role in this regard. We mentioned energy communities that would help build decentralised energy grids and make energy use more efficient (architecture of energy grids, etc.). In short, we propose that it is mainly at the level of the community, where the level of climate change mitigation will be decided.

Members of the OPC

Enrico Benetto

"In joining the OPC, I am motivated to share my experience in quantitative assessment of the environmental impacts generated by human activities and technologies, to contribute to the evaluation of climate policies and the definition of improvement recommendations. In particular I intend to focus on the quantitative assessment of the positive and negative effects of carbon emissions, of policies on socio-technical systems, on industry and vice versa, so to consider the causal relationships between policy actions and expected benefits in relation to climate targets in the analysis. Considering the possible side-effects of climate policies, e.g., on environmental impact categories other than climate change (e.g., biodiversity) as well as on social aspects is also very central in my contribution to the OPC."

My core research interest is in developing science-based methods and indicators to orient sustainable decarbonisation pathways towards climate targets. I am leveraging 25 years of leadership experience in RDI institutions in the field of environmental life cycle sustainability and risk assessment of products, technologies and policies and broad range of experiences in providing assistance with decision-making for industry and public policy. On the academic side, I have contributed to the scientific literature, co-authoring 120+ peer reviewed scientific papers, 150+ scientific conference proceedings, 18 chapters in volumes with ISBN and editing one open access book which has been accessed 1M+ times. On the impact side, I have contributed in generating and disseminating new knowledge in 30+ European research projects and 25+ collaborative research partnerships with SMEs, policy makers and large industries. I am keen to broadly contribute to enhance the consideration of sustainability in society. I have developed research and strategic partnerships with national Ministries and international institutions (e.g., World Alliance for Efficient Solutions of Bertrand Piccard). Further, I served as advisor for the TEG on Sustainable Finance of the EU Commission. I am currently serving as advisor in different Boards (e.g., Spuerkees, Greenworlder, IRT M2P).

Sabine Dörry

"Climate change is affecting and will continue to affect living conditions in Luxembourg. My motivation and ambition for the OPC is to provide information on the complexities, especially in relation to climate and sustainable finance, and make scientific knowledge accessible. By actively addressing the roots and causes of climate change, I also see many opportunities for Luxembourg's sustainable future, its society, its environment, and its economy."

Sabine Dörry is an economic and financial geographer. She is a senior researcher working at the Luxembourg Institute of Socio-Economic Research (LISER) and a founding and board member of the FINGEO Network, the Global Network on Financial Geography. Building on previous research positions at and academic visits to the universities of Frankfurt am Main, Oxford, Amsterdam, and Singapore, her current work focuses on the financial industry, and its organisation in and influence on leading financial centres. Sabine is interested in developing alternative ways to analyse the global financial system. This includes how shifts towards 'sustainable' finance and increasing technologisation affect financial activities, (redesigning) financial institutions, and (rebuilding) regional economies.

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Photo: © Spuerkeess - Flavie Hengen

Claire Dupont

"Responding effectively and fairly to climate change is a daunting task: Nothing less than the transformation of our underlying societal, cultural, and technological systems along with fair individual efforts will do. Everyone has a role to play."

Claire Dupont is political scientist, whose research focuses on EU and international climate and energy politics, policy, and governance. She currently works as associate professor of European and international governance at Ghent University, Belgium. She also serves as the Vice-Chair of the Scientific Committee of the European Environment Agency. Originally from Ireland, Claire moved to Brussels, Belgium, in 2008, to pursue her PhD at the Vrije Universiteit Brussels, in which she assessed the integration of EU climate and energy policy frameworks.

"Clearly, our knowledge systems also need to change to contribute to the necessary transformation, including by becoming more engaged and embedded in policy and societal processes. I am honoured to have the opportunity to play a role in these efforts through the work of the OPC."

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Andrew Ferrone

"The solution to global climate change has to be addressed as a global effort, however in practice every single action counts. These need to include incremental efforts, based on fossil-free technologies, as well as behavioural changes. At the same time, further fundamental societal changes and lifestyles changes must occur in order to achieve a full decarbonisation of society, in conjunction with all of the Sustainable Development Goals."

Andrew Ferrone is a physical climate scientist by training and works mainly at the climate science policy interface. He is currently the Head of the meteorological service at the Administration of Technical Agricultural Services (ASTA) in Luxembourg. He is also the Permanent Representative to the World Meteorological Organisation (WMO), the head of the Luxembourgish delegation to the Intergovernmental on Climate change (IPCC) and coordinates the team of negotiators for the European Union on Science issues under the United Nations Convention on Climate Change (UNFCCC). Andrew completed his PhD at the Université catholique de Louvain, on the topic of aviation and climate change in Europe: from regional climate modelling to policy-options.

"The societal changes that are necessary can only happen if we take collective decisions based on the best available science. To do so it is important to bridge the gap between the scientific community and the decisions makers as well as the general public. The OPC should play a key role in this endeavour in Luxembourg, and I am honoured to have the opportunity to be part of this work."

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Ariane König

"Let's work for healthy ecosystems, social systems, and lifestyles!"

Ariane König is a Research Scientist at the University of Luxembourg, where she and her team are engaged in research projects to facilitate and learn from social processes with experts and stakeholders to address complex sustainability challenges. The research focus is on food and water and land-use systems as well as the tight interplay between the two. We seek to understand how developments and transformations within the spheres of society, technology, ecology, and the personal sphere are interdependent, and which might be prominent leverage points for deliberate transformations for a more sustainable society. König also built and coordinates an innovative study programme in 'Sustainability and Social Innovation' that is open to students and professionals. In addition to be a member of the Observatoire, König is also a member of the European Statistical Advisory Committee and has completed two terms as a member of the national Conseil Supérieur pour un Développement Durable.

König obtained her Bachelor and Ph.D. at the University of Cambridge, Emmanuel College, and first worked on risk regulation for a leading multinational life science corporation. Thereafter she joined the universities of Harvard and Oxford, where she conducted research and taught post-graduate and executive training courses on governance of new technologies and risk, with a focus on sustainable agricultural food production. She has also worked as an independent scientific consultant for the OECD, the European Commission, and EU research consortia. She has over 50 publications, her most recent book 'Sustainability Science: Key Issues' was published by Routledge in 2018.

"Sustainability requires transforming how we think of and relate to ourselves, other people, and the environment we live and work in. That's not easy given our social system and infrastructures produce patterns of thought and behaviour that are hard to escape. The courses, study programme, and research projects I have built since 2010 serve to equip agents of change, such that we can better recognise leverage points for local and systemic change and evaluate and learn from these changes in a networked manner. This can involve citizen science, scenario work and other means. With my research team, and personally, I work to improve how we engage with and regenerate healthy water, soil, and biodiversity, in Luxembourg and beyond. In my organic garden I am proud to host countless lizards, diverse mice, a slowworm, and a rare smooth snake, who seem to seem to enjoy the many insects and packaging- and logistics-free vegetables and fruit there as much as my family and I do."

Mirjam Kosch

"In 2050, I will be 65 years old and looking forward to my retirement. In the same year, at the latest, we must achieve net zero greenhouse gas emissions in order to limit global warming. It is my professional goal to be able to say at my retirement: The world has managed to stop global warming - and I have contributed to it!"

Mirjam Kosch is an enthusiastic environmental scientist and completed her doctorate in economics at ETH Zurich on climate policy in the electricity sector. As part of her doctoral thesis, she empirically analysed the impact of renewable energy subsidies and carbon pricing. Currently, she is working at the Potsdam-Institute for Climate Impact Research on the impact of fuel and carbon prices on electricity prices as well as on the expansion of the European emissions trading system and its interplay with different policy instruments. As a modern climate economist, she is convinced that carbon pricing should be a central instrument of climate policies but needs to be complemented by a broad policy mix.

"Ever since my Bachelor studies I have been fascinated by the science-policy interface. Only when both sides actively engage in the dialogue between scientists and policy makers, can we really make a difference. Small countries where people know each other, like Luxembourg or my native country Switzerland, can lead the way as pioneers in this field. I am thus very happy to be part of the OPC and hope to make a contribution to mutual understanding between the two worlds."

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Jean-Pascal van Ypersele

"I turned 65 years old in 2022, and I want to pass on what I have learned throughout my career as a climate scientist, without embellishing reality or making it sound all doom and gloom. In the institutions and groups where I have the chance to be active, including the OPC, I will continue to advocate for respect for the environment and all forms of life, human rights, equality of women and men, truth, justice, science, listening, empathy, diversity, and inclusiveness.

I would like to put my energy and time at the service of having the IPCC's conclusions seriously taken into account by political decision-makers, economic actors, the education sector, and citizens. In doing so, I wish to remind people that there are many solutions to the various challenges facing humanity, and to support young people who want to build a better world."

Jean-Pascal van Ypersele is full professor of climatology and sustainable development sciences at UCLouvain (Université catholique de Louvain, Belgium) and member of the Académie royale de Belgique. A physicist and climate modeller who worked at NCAR (National Center for Atmospheric Research, USA), he has jointly published many papers with natural and social scientists on climate change and sustainable development at global and regional scales, and this for forty years. He has been extensively involved in the IPCC since 1995 and was IPCC Vice-Chair from 2008 to 2015. He co-authored the first quadrennial UN Global Sustainable Development Report (2019) and was a member of the EU Mission Board on Adaptation to Climate Change, including Societal Transformation (2019-2021). He has participated in most UN conferences on climate issues since 1979, including almost all COPs. He regularly briefs Heads of States and Governments and is occasionally consulted by Greta Thunberg.

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Photo: © Kiara Worth

List of footnotes

[1] Each finding of the IPCC reports is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, medium confidence.

[2] IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

[3] Loi modifiée du 15 décembre 2020 relative au climat. http://data.legilux.public.lu/eli/etat/leg/loi/2020/12/15/a994/jo

[4] Règlement grand-ducal du 22 juin 2022 déterminant les allocations d'émissions de gaz à effet de serre annuelles pour la période allant jusqu'au 31 décembre 2030 des secteurs visés à l'article 5 de la loi modifiée du 15 décembre 2020 relative au climat. http://data.legilux.public.lu/eli/etat/leg/rgd/2022/06/22/a328.

[5] PLAN NATIONAL INTÉGRÉ EN MATIÈRE D'ÉNERGIE ET DE CLIMAT DU LUXEMBOURG POUR LA PÉRIODE 2021-2030 https://mea.gouvernement.lu/dam-assets/energie/energie-renouvelable/Plan-national-integre-en-matiere-d-energie-et-de-climat-du-Luxembourg-2021-2030-version-definitive-traduction-de-courtoisie.pdf . Il est basé sur le règlement (UE) 2018/1999 sur la gouvernance de l'union de l'énergie et de l'action pour le climat.

[6] Loi modifiée du 15 décembre 2020 relative au climat. http://data.legilux.public.lu/eli/etat/leg/loi/2020/12/15/a994/jo

[7] Relevant legal texts: Nomination of OPC members: https://legilux.public.lu/eli/etat/adm/agc/2021/09/29/b3859/jo; Remuneration of OPC members: https://legilux.public.lu/eli/etat/leg/rgd/2022/05/27/a254/jo

[8] Bilan provisoire des émissions de gaz à effet de serre 2021 https://environnement.public.lu/fr/klima-an-energie/changement-climatique/inventaire-ges/proxi-ges.html

[9] IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

[10] Nathan J. Benett, Jessica Blythe, Andres Cisneros-Montemayor, Gerald G. Singh, and U. Rashid Sumaila. 2019. Just Tansformations to Sustainability. Sustainability. 11, 3881-3899.

[11] Stevenson, R.B., Nicholls, J. & Whitehouse, H. What Is Climate Change Education?. Curric Perspect 37, 67–71 (2017). https://doi.org/10.1007/s41297-017-0015-9

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Acronyms

AR6	6th Assessment Report
ASTA	Administration of Technical Agricultural Services
CFB	Temperate Oceanic Climate
DALYs	disability-adjusted life years
EIB	European Investment Bank
EIF	European Investment Fund
ESG	standards of environmental, social, and governance
EU	European Union
EU PRIMES	Energy system model designed to project the energy demand, supply, prices, trade and emissions for European countries and assess policy impacts.
EV	electric vehicles
FCCF	Forestry and Climate Change Fund
GDP	Gross domestic product
GHG	Greenhouse Gas
ICFA	International Climate Finance Accelerator
IEA	International Energy Agency
IFC	international financial centre
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and products use
LCFP	Luxembourg-EIB Climate Finance Platform
LIST	Luxembourg Institute of Science and Technology
LULUCF	Land Use, Land-Use Change and Forestry
NBS	Nature Based Solutions
OPC	Observatoire de la politique climatique / Climate Policy Observatory
PNEC or NECP	Plan national intégré en matière d'énergie et de climat
RE	renewable energy
sc-PDSI	self-calibrated Palmer Drought Severity Index
SDGs	Sustainable Development Goals
SUV	Sports Utility Vehicle
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

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