LUXEMBOURG IN TRANS

Stage 1:
Luxembourg in Transition

Date 04.01.2020
Client Ministère de l'énergie et de l'aménagement du territoire
KCAP Architects&Planners
+ Arup
+ Cabane Urbane Strategien

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Team

A multi-disciplinary approach to complex design issues

It is with pleasure and excitement that we submit our proposal to work with you on spatial visions for a transition framework for a zero-carbon and resilient future of the Luxembourg Funtional Region

We believe that you will find within this booklet the work of an exceptional team that has a long track record of working together, working in various cultural contexts and hopefully now with you in Luxembourg producing spatial, environmental and programmatic strategies of outstanding quality around the world. We are experts in our fields and many of our projects are widely regarded as benchmarks in urban planning, urban design, engineering, architecture and landscape. The awards, accolades and publications of our collective body of work attests to our commitment to excellence, both as a team and as individual offices.

We sincerely hope to work with you on the next two phases of this project and are highly motivated to bring in our expertise.

KCAP Architects&Planners
Urban design
Urban planning
Territorial planning
Architecture
Landscape

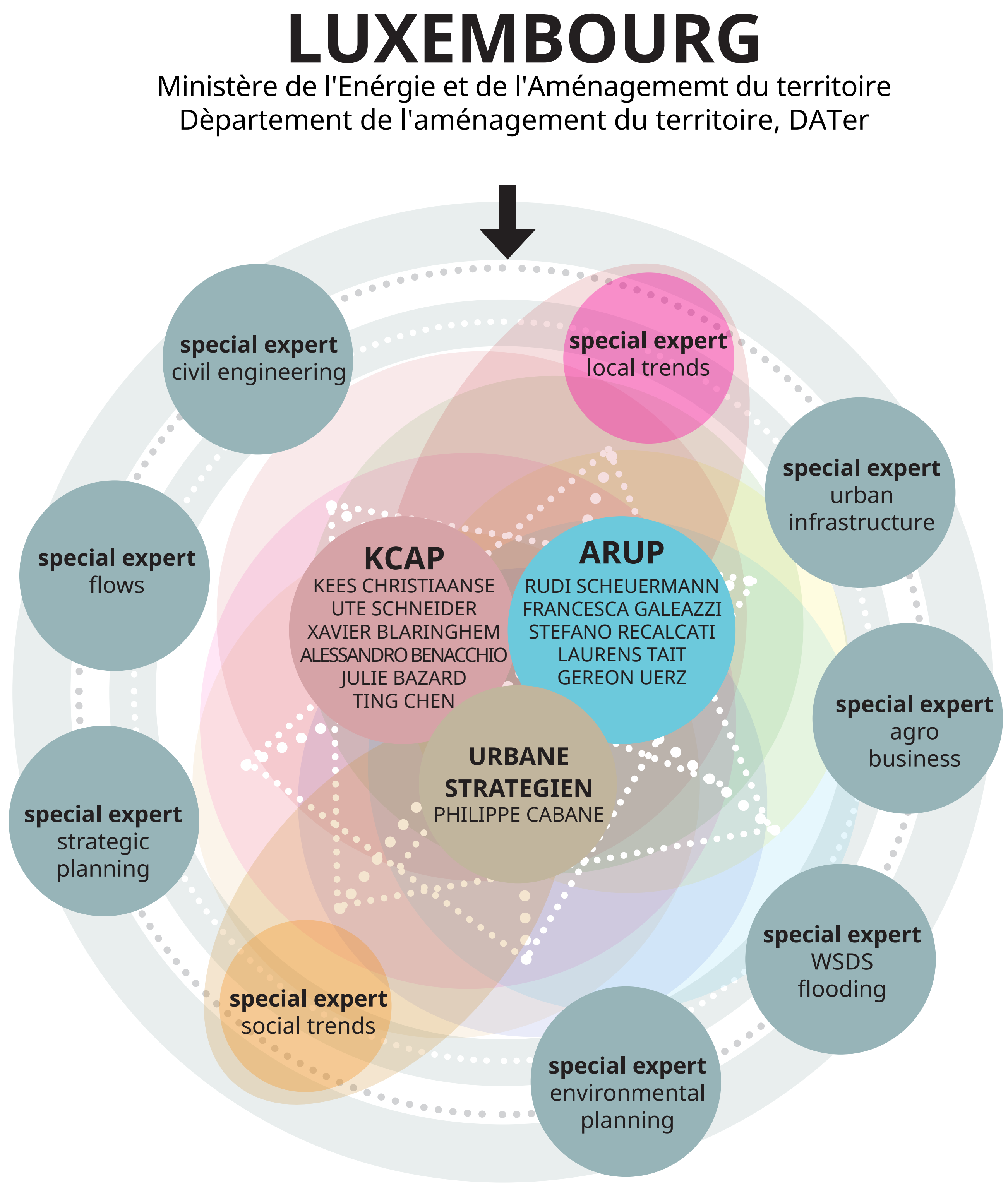
Arup
Zero-Carbon & Decarbonisation
Resilience
Demography and contextual trends
Strategic Planning & Economics
Active Transport Strategy

CABANE Urbane Strategien
Sociology
Urban development
Strategic planning
Transboarder planning

External experts:

Prof. Dr. Marco Mazzotti
Professor of process engineering at ETH Zurich. He was coordinating lead author of the IPCC Special Report on Carbon Dioxide Capture and Storage (2002-2005). He leads the ETH Zürich's Energy Science Center (ESC). He is a specialist of technologies and systems to reduce carbon dioxide emissions across sectors and to achieve carbon-neutrality.

Christopher Christiaanse MSc
Mechanical Engineer who specializes in the strategic development of renewable energy infrastructure. Since 2018 he works as a consultant for the Dutch company DAREL, where he works on several large-scale energy projects in the industrial complex surrounding the Port of Rotterdam.



Guidance to the document

Our report is organized to offer you answers in the following way:

In Chapter I you will find a clear statement of our Radical Pragmatism ambition and goals;

In Chapter II you will find an analysis of our emerging conclusions on the critical contexts that are in place in Luxembourg;

In Chapter III we seek to elaborate on the contexts presented by exploring, along the thematic lines of the different sectors, the key domains that will give us a potential to achieve the Ambition set. This is organized by analysis (our reading of the quantitative data and evidence), an introduction to the Strategy & methodologies possible, and finish with the Key Metrics of transition that we believe Luxembourg should focus on.

In Chapter IV we conclude with a presentation of a hierarchy of interventions, in the spirit of Radical Pragmatism.

In this way and through these chapters we describe our understanding of the context and the focus needed for a design and planning strategy compatible with the objective of ecological transition.

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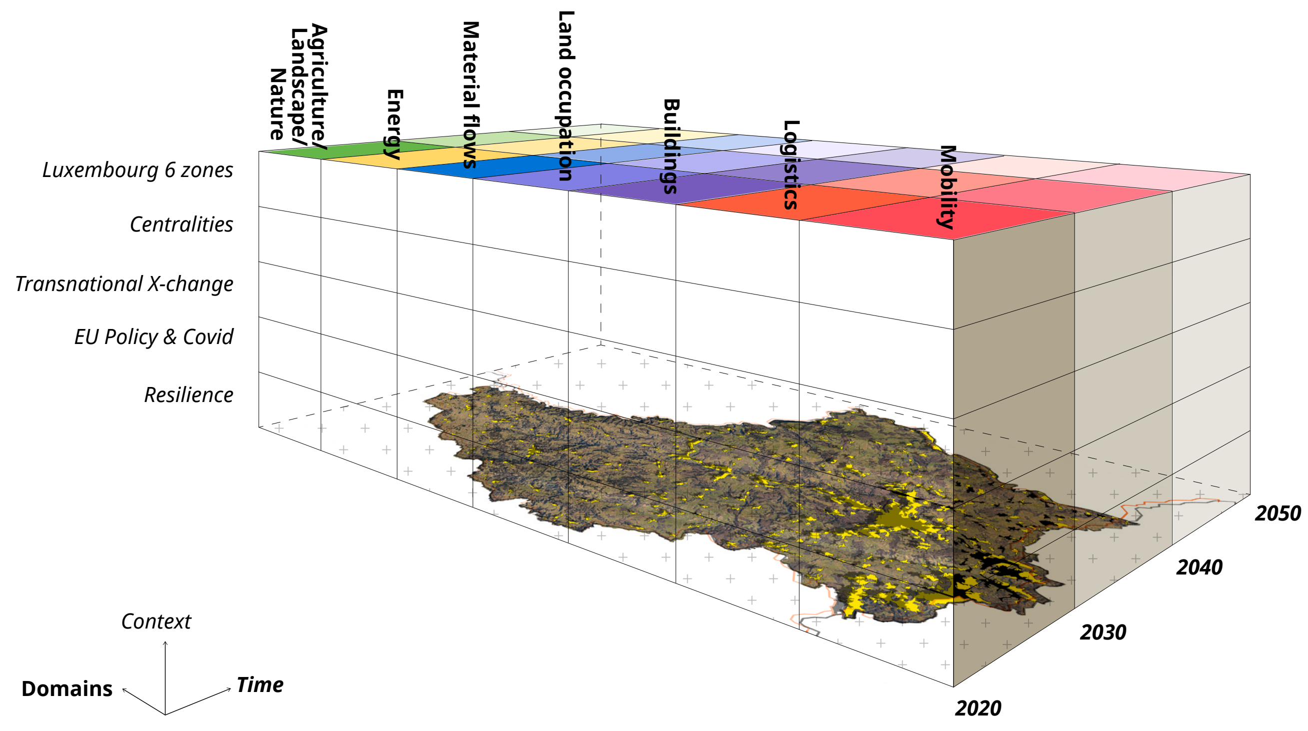
Executive Summary

Radical Pragmatism
"To support Luxembourg's vision to approximately halve greenhouse gas emissions by 2030 and to become carbon neutral by 2050, we would like to address primarily those domains, which have the highest impact on greenhouse gas generation, and to develop pragmatic tools to influence and transform them. In this way, we hope to enable a sharp reduction of GHG emissions in the coming years via concrete facts on the ground, which may establish an improved physical condition and a renewed mindset, which in turn will trigger and boost innovative solutions, beyond what is known and conceivable today."

Contexts
We will investigate these domains in six geographies (the city of Luxembourg, the urbanized landscape in the South, the culture landscape in the middle, the Ardennes in the North, the border zone and the transnational region). We will specifically look into the aspect of (poly-) centrality and transnational exchange as a base for sustainable urban development. We will review the context of European Union policies. And, last but not least, we will consider the aspect of resilience as a contextual factor, in which specifically (inter-)dependencies of infrastructures and flows, but also the aspect of education and behaviour are investigated - because sustainable technologies and policies do not work without compliance.

Domains
We will focus on those domains with the largest potential leverage. These domains include mobility & logistics, buildings & land occupation, material flows & energy. And we will also take a bird's eye perspective into the relation agriculture-landscape-nature.

Consolidation
The Contexts and Domains together are integrated into a weave which serves as a base for our consolidated strategy.



1.

AIMS

Aims: Radical Pragmatism

Aim

Our aim is to help Luxembourg to achieve the goal stated by its National Energy and Climate (ENCP) Plan: the reduction of Greenhouse gas emissions by up to – 55% until 2030 in comparison to 2005 (Le Gouvernement du Grand-Duché de Luxembourg, 2018). Furthermore, also linked to the goals of the European Green Deal, our project will aid Luxembourg to achieve carbon neutrality by 2050. (European Commission, n.a.).

While Luxembourg made considerable efforts towards reducing its ecological footprint over the last decades – a reduction of approximately – 17% in comparison to 1990 levels, it currently has one of the highest levels of carbon dioxide emissions per capita in the world and the highest among European countries. (World Bank, n.a.). The following chart presents a breakdown of greenhouse gas emissions per sector in Luxembourg in 2016.

Radical Pragmatism

Today, everywhere «Grand X» studies are emerging. In the recent past we have seen studies for Grand Paris, Grand Geneva, Grand Brussels, Grand Berlin and now we are working on Grand Luxembourg, dealing with a whole country in a transnational setting, although its population is generally less than the mentioned cities.

These studies generally excel in developing a comprehensive future vision, of which the sheer scale, complexity and interdependency of proposed strategies and scenarios make them very inspiring and instructive, however they often lack direct pathways to implementation and the creation of facts on the ground. Our approach therefore is not to build a complex model of interrelated phenomena and a subsequent set of overarching, holistic ambitions. We will develop a general overarching vision, but from there we prefer to go for a radical pragmatic approach:

Our driver in this phase is to identify which phenomena have the greatest impact on the production of greenhouse gas emissions and the climate, and in what way can we develop practical policies and tools to reduce this impact.

Luxembourg is a small country with clear borders, an overseeable population number, a prosperous market-economy and a transparent social-democracy. The country already disposes of quite sophisticated environmental and sustainable policies. This condition forms an excellent base to make a clear diagnosis of systemic and climate-related challenges. It also provides an excellent base to propose strategies for change and mitigation, which could relatively easily feed into decision-making processes and consequently lead to implementation. The basic characteristic of sobriety in Luxembourg's culture provides a certain guarantee that proposed policies will be treated with efficiency.

Concerning climate and environment, we are aware that there are domains that are responsible for a significant share of greenhouse gas emissions. In this document, we will analyse sectors in Luxembourg that encompass mobility and logistics, building and land occupation, materials flows, energy, agriculture and nature and will also analyse the underlying, more contextual domains that are unique to Luxembourg and its region, such as the transnational context, the six-zones of the country, its poly-centrality, resilience and sustainable behavior.

Stage 1 of the Luxembourg in Transition project asks to demonstrate that we understand and accurately use the quantitative data and objectives relating to the two simultaneous goals concerning urban society in the 21st century: the development a carbon-neutral society (by actively decarbonizing and reducing GHG emissions), and the resilience to the effects of climate change, either suddenly occurring or slowing developing.

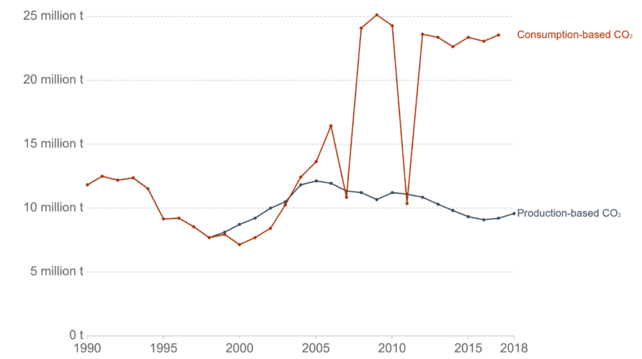


Fig. I.1: Production vs. consumption- based CO_2 (ourworldindata.org)

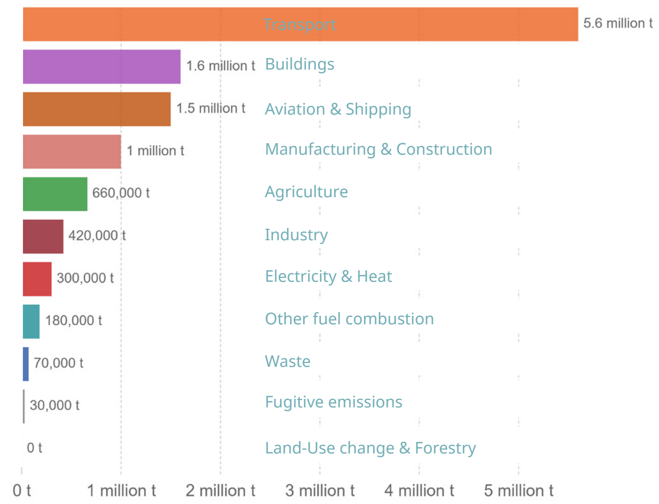


Fig. I.2: GHG emissions in million tonnes by sector Luxembourg 2016 (ourworldindata.org)

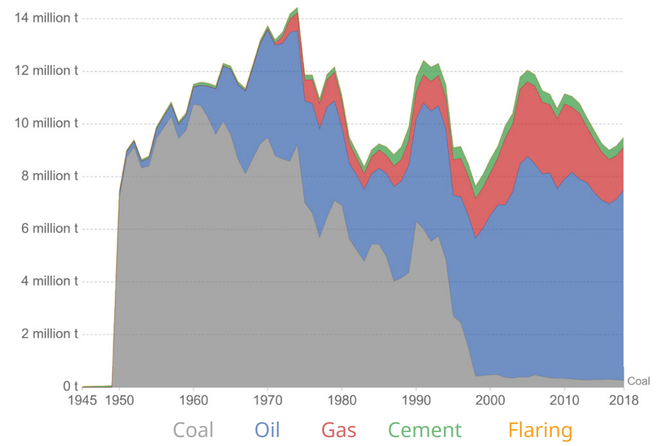


Fig. I.3: CO_2 emissions by fuel type, Luxembourg 2016 (ourworldindata.org)

II.

CONTEXTS

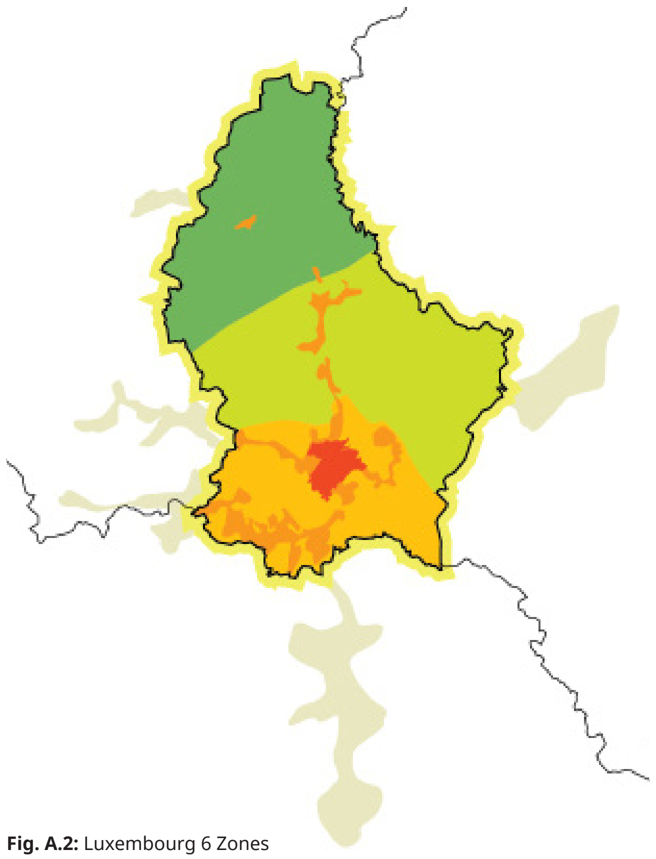
A. Luxembourg 6 Zones

There are many ways to see and characterise Luxembourg, as a state, either as a kind of "Swiss canton", or as a city state with surrounding countryside. An appropriate way of seeing Luxembourg is as a region within a Europe of regions. And evidently, the city of Luxembourg is a member of the large, fine-meshed network of middle-sized cities, which covers western Europe.

Within the state boundaries, three geographical zones can be identified: the North, including the Ardennes, its nature and forests; the Middle, mainly consisting of a cultural landscape where agriculture dominates; the South, comprising most dense settlement in an urbanised landscape setting. In addition, we have defined the main border zones as an additional category. Together with the transnational embedment we see six physical territories of operation for our investigations:

- The Transnational region: LuBeDeFr
- The Border: transitional zones
- The North: Ardennes, forest
- The Middle: agriculture, cultural landscape
- The South: urbanised landscape
- Urban area including Luxembourg City

Fig. A.1: Luxembourg within the network of middle-sized cities in western Europe



Transnational region (main catchment areas)
Border
North
Middle
South
Urban area
Luxembourg City

Fig. A.2: Luxembourg 6 Zones

B. Centralities

Contemporary urbanization is characterized by poly-centrality. While up-scale, Luxembourg is a complementary node in the poly-centric network of Western-European cities and part of a transnational region, down-scale it is also organized in a poly-centric way with many nodes within the larger agglomeration of Luxembourg, like Kirchberg or Esch-sur-Alzette, surrounded by more scattered villages. These nodes are of great importance for a sustainable urban future of Luxembourg, as they generally are historically embedded in the cultural landscape at historical road intersections and have a historical core with a diversity of scales, buildings, services and amenities. They generally are also hubs of public transport.

Such a poly-centric configuration may show certain hierarchies and focuses, differentiating in for instance: Educational node (Belval), administrative node (Kirchberg), cultural node (Luxemburg city), etc., leading to a complementarity of functional nodes in a poly-centric urban landscape.

This observation may lead to proposals in which these centralities are conceptually reorganized, for instance the nodes between Mont Saint Martin, Esch-sur-Alzette and Dudelange could be reconfigured into a special urban zone, or in another urbanization model.

1km region from the train station, can be easily accesible within 10 min cycling
Apartment
Other residential
Infrastructure
Commercial
Industrial
Remarkable/religious buildings
Train station
Health
School
Public buildings
Mixed-used/multi purpose
Sport center
Administration

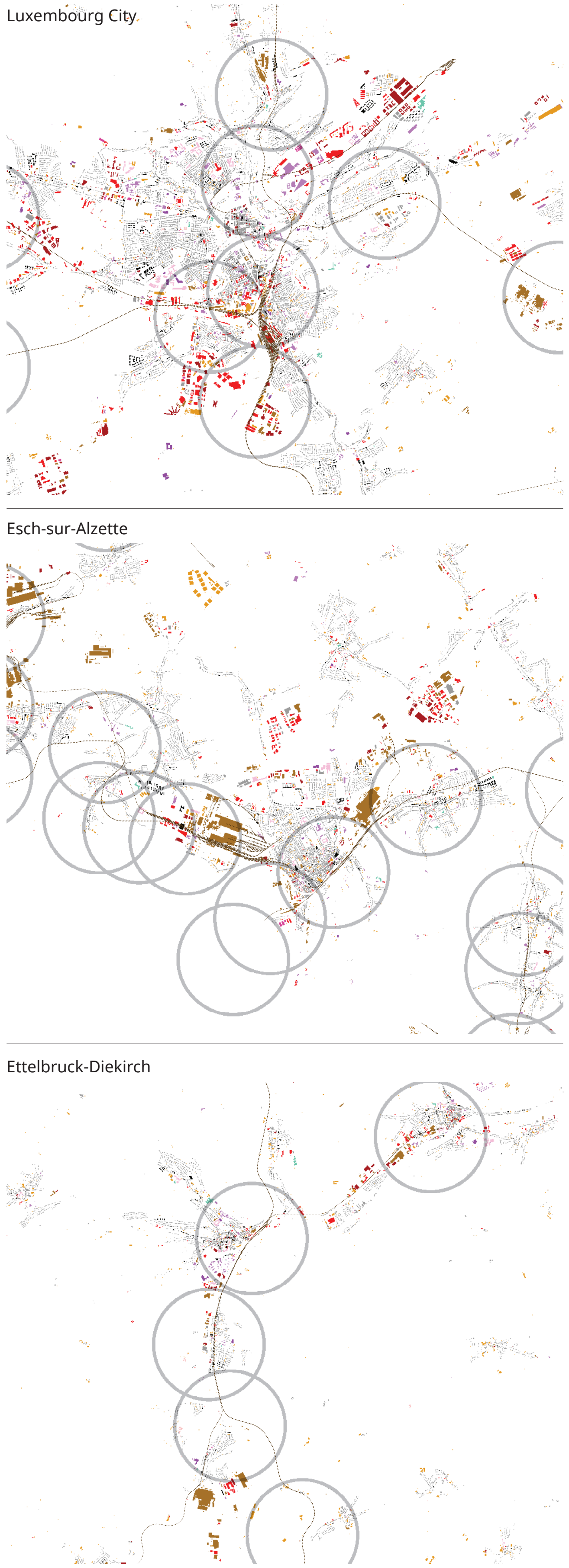


Fig. B.1: Zone with high accessibilities via public transport and active mobility

C. Transnational X-changes

Arrival City Luxembourg

Luxembourg may in a sense be characterized as an arrival city. As the demographic prevision and the need for workers in Luxembourg shows, there is a big gap between the demand for high qualified workers and their availability. For this reason, Luxembourg cannot exist without continuous migration and transborder commuters, which are currently estimated at 200.000, equal to 45% of the total work force. Dominated by motorized individual transport, transborder commuting presents a major challenge for Luxembourg's 2050 goal of climate neutrality. (Fig. C.1)

A 'couronne' of commuter settlements

Near the boundaries of Luxembourg's territory, two important commuter clusters can be identified: the French and Belgian cluster in the southern part around Thionville, Esch, Arlon; and the German cluster along the border south of Trier (Fig. C.1). The Grande Région of SaarLorLux can be considered as a network of smaller co-cities in a wider «metapolitan» context (ASCHER, 1997).

A specific phenomenon that can be observed in the transborder situation in Luxembourg is a demographic change in the urbanized areas along the border. Transborder commuters are traditionally settled in the border regions of France, Belgium or Germany. They cross the borders to work in Luxembourg because of the better job-opportunities and higher salaries.

During the last decade of Luxembourg's expedited growth, a distinctive settlement movement away from the city has been taken up momentum: On the one hand, rising costs of living in the city of Luxembourg have pushed people into the countryside (and suburbs?), and on the other hand, transborder areas in France, Belgium and Germany have been densifying at a high pace because they offer «best of both worlds»: Affordable housing and living on one side, better salaries and cheap gasoline and commodities on the other side.

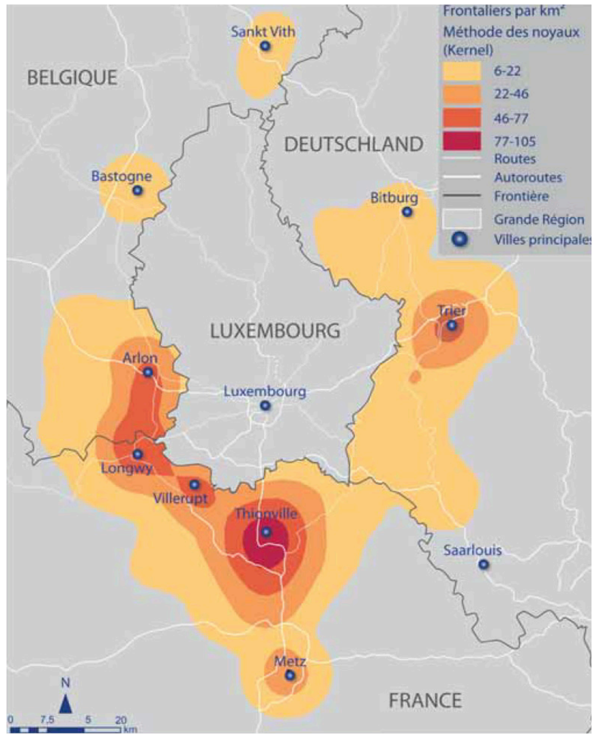


Fig. C.1: Densities of transborder commuters 2012. (Schmitz et alt. 2012)

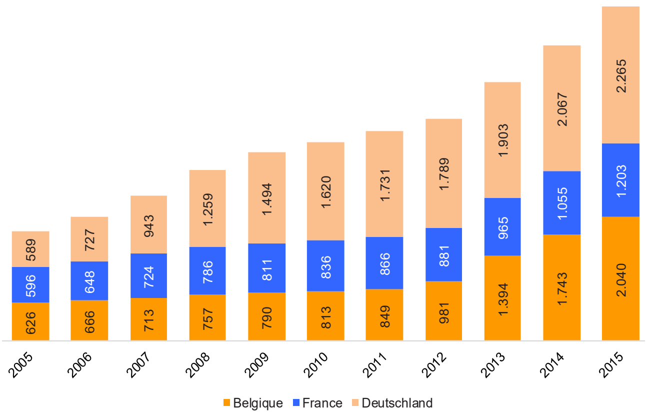


Fig. C.2: Atypical transborder commuters 2011-2015. (IBA / OIE, 2019)

There are two types of groups that fuel this development: a-typical transborder commuters and expatriates:

A-typical transborder commuters

A-typical commuters are Luxembourg nationals who settle in a neighboring country because of the lower costs for housing and food. This trend will continue as long as Luxembourg does not offer sufficient affordable housing. Luxembourg has experienced an increase of 300% in a-typical transborder commuters within the last 10 years (Fig. C.2). As long as the differences in costs of living between Luxembourg and the neighboring countries remain high, and mobility costs relatively low, this type of «urban escape» across the borders will continue to influence the demographic structure of traditional commuter settlements, thereby increasing the overall transborder transport.

Expatriates

Expats have long been seen as a driver of gentrification within the city of Luxembourg. They generally earn above-average salaries, allowing them to spend more for a home in the city. However, this group is increasingly starting to settle in transborder regions too. Since they are less attached to a traditional perception of borders, they choose their new hometowns more rationally, deciding that the increase in purchasing power there is worth the transborder commute.

A transborder urban concept

Working in Luxembourg and living in Germany, France or Belgium is attractive as long land in border regions remains relatively cheap, and individual mobility remains more attractive than public transport. (Fig. C.3) The transborder urban space of Luxembourg, with its territorial gaps in economic, political and cultural development, causes a-specific concentrations of commuter settlements in the transborder area. The chances to bring these commuters back to Luxembourg by offering more affordable housing are limited, as prices along the borders remain attractive. This means that alternative transport modes are required to control the flow of transborder commuters.

For that reason, Luxembourg has started constructing new tram lines: The line between Esch and Luxembourg city will be completed in 2028, significantly expanding public transport capacity between the French border region and the city center. Together with the

Fig. C.3: Transborder commuters settlements (www.wort.lu)

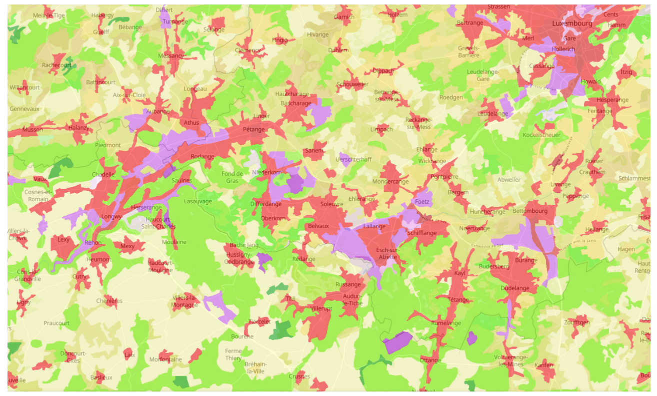


Fig. C.4: The 2018 Trinational urban footprint along French and Belgien borders. (map.gis-gr.eu)

various opportunities some favorable conditions would favorise a development of new urban concept in den transborder «couronne» (Fig. C.4).

On the institutional level of governance, the Grande Région (grosseregion.net) represents a valuable frame for a greater regional development. For transborder urban developments, there is currently just one cooperation: the GECT Alzette Belvals. The organisation is represented by members from Luxembourg and France. It is more focused on the communities. An institution with competences like the Eurodistrict Saar-Moselle is missing.

D. European Union Policy / Learning from COVID-19

European Union Policy

As one of the six founding member states of what is now the European Union, Luxembourg has had a significant role in shaping the direction, agenda and goals of the EU's policy frameworks over the past decades.

Luxembourg's small size doesn't allow it to be to be self-sustaining and therefore it heavily relies on cross-border transfer of energy, goods, services and people, which has led to early integration of infrastructure with neighboring regions: it boasts an impressive cross-border infrastructure, ranging from the transport of energy to goods and people.

As for all EU member states, many of the elements that influence Luxembourg's GHG emissions are at least partly governed by EU policy frameworks, such as:

- The Common Agricultural Policy (CAP), a corner stone of the EU since the 1960's, contains a vast system of agricultural subsidies, and covers policies regarding environmental protection, biodiversity and the development of rural areas;
- The Renewable Energy Directives (RED) first took effect in 2001, mandating the level of renewable energy use for each member state for a given target year, for example determining how big the percentage of biofuels in transport must be;
- The Emission Trading System (ETS), which was launched in 2005 puts a price on emissions from factories, power stations and other installations that are collectively responsible for 40% of EU GHG emissions.

Fig. D.1: Night lights in Europe (European Space Agency)

Under the Presidency of Ursula von der Leyen, the European Commission has grown more assertive on pathways to European climate neutrality: Under the umbrella of the European Green Deal, a set of policy initiatives was launched with the aim to become the first climate-neutral continent in 2050. A first target for 2030 is to achieve at least 50% reduction in GHG emissions, with respect to 1990 levels. The European Parliament has voted to support the deal as well, with requests for even higher ambitions.

Under the European Green Deal, existing laws and policies will be reviewed on their climate merits, and new policies will be introduced around the topics of:

- Clean energy
- Sustainable industry
- Building & renovation
- Farm to fork
- Eliminating pollution
- Sustainable mobility
- Biodiversity

Not at least because of the shared goal of climate neutrality in 2050, our approach to drafting Luxembourg's strategy uses relevant EU policies as guidelines. Building upon these policies allows us to deliver a tailor-made, flexible strategy that aligns Luxembourg's national efforts with those of adjacent regions. This will significantly increase effectiveness and decrease double work. Regional cooperation and integration will maximize impacts and cost-effectiveness of new infrastructure developments.

Learning from COVID-19

The COVID-19 pandemic has disrupted many aspects of society. It set off a worldwide economic slump and, while the road to recovery appears to have been found, its impacts are still evolving. The effects are multi-dimensional, affecting health, economic and social crises. Moreover, the long-term effects on cities and rural areas are slowly becoming apparent. For example, recent decades have shown a steady global trend of migration to cities. But the pandemic is putting density and lack of green space into doubt, with unknown consequences for future settlement patterns. Working from home is on the rise, while business travel and related mobility services are in low demand. Customers are increasingly turning to digital channels – from convenient food deliveries to streaming services. Some inherent changes are already visible: a major urban policy response during the pandemic has been the rapid implementation of new bike lines in cities like Paris, Milan and Bogotá. For the specific case of Luxembourg:

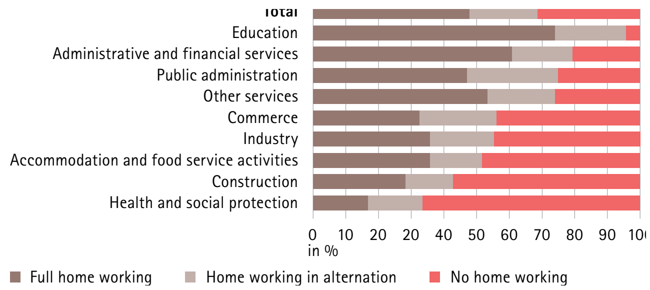


Fig. D.2: Home working compared to active people during the lockdown period, Luxembourg (STATEC, 2020)

- Electricity consumption dropped by 14% during the lockdown and has stabilized at 8% lower than previous years since then. This is explained by the reduction in electricity production due to limited movement and home office.
- Rail transport passenger numbers dropped by 75% initially, and has rebounded to 50% of the pre-pandemic levels
- Fuel sales initially dropped by 62% and stabilized at -16% with respect to pre-pandemic figures.

The Covid crisis thus provides us with vital indicators for a future where domestic life, working, entertainment and recreation, movement and logistics may be distributed more effectively and less environmentally damaging.

E. Resilience

“Making cities and human settlements inclusive, safe, resilient and sustainable” is the UN’s Sustainable Development Goal that deals with the challenges of rapid urbanization, and is therefore an integral part of the UN Agenda 2030. Resilience is the capacity of individuals, communities, and systems to adapt, survive, and grow in the face of stresses and shocks, and even transform when conditions require.

In general, all contemporary cities face various types of risks, both as frequent and infrequent events, with either sudden or slow-onset natural or man-made hazards, that can occur both globally and locally.

Luxembourg’s ability to present itself as an attractive and friendly environment for inhabitants and visitors can be disturbed by shocks and stresses. Examples include ecological challenges, natural disasters, deficits in infrastructure capacity or the long-term consequences of the COVID-19 pandemic on citizen’s well-being.

City Resilience Index

The City Resilience Index (CRI), developed by Arup with support from the Rockefeller Foundation, provides a comprehensive, technically robust framework for measuring and assessing city resilience. It is a powerful tool that helps cities understand and respond to identified challenges in a systematic way. It incorporates a framework used in more than a hundred cities to guide their resilience journey.

The following list provides an indication of stresses and shocks that were identified for Luxembourg in a preliminary analysis using the CRI.

Stresses

- ***Steady cross-border-population movement*** The phenomenon of frontier work in Luxembourg is exceptional in more than one way. First of all, due to the high relative share of frontier workers in all the jobs held in the country (around 45%), but also because of the speed of its growth; the number of cross-border workers increased by 34% between 2007 and 2017 (STATEC, 2017).

- ***Chronic traffic congestion*** Luxembourg is a rich country that is heavily car dependent. There are 647 cars for every 1,000 people, representing one of the highest ownership rates in the world according to the International Road Federation (Forbes, 2018), which results in a high dependency on road infrastructure. (See mobility & logistics)

- ***Rising prices of housing*** Statistics show the average price of an apartment (including both newly constructed as well as existing properties) in the country of Luxembourg is continuously rising, year-on-year. From 2010, average prices increase by approximately 46%. (Statista, 2020). Average rent is on the rise too, according to atHome, having increased by about 6% during the past 12 months. (RTL.lu, 2020)

- ***Poverty and poverty risk*** With 18.3% of the population at risk of poverty or social exclusion, Luxembourg has a 1,5% higher poverty rate than the average of in the EU (Eurostat).

- ***Ageing of local population*** In 2013, Luxembourg’s crude birth rate was 11% and the fertility rate was 1.55 children per woman. This is equal to the UE28 average, which is significantly lower than the replacement level of 2.1. The crude death rate was 7% (STATEC, 2013). This trend fuels concerns about the funding of the retirement system, the health care system, family policies and intergenerational solidarity.

- ***Energy system inefficiency*** Luxembourg’s energy system is characterized by a high import dependence and a reliance on fossil fuels, which results in a relatively low energy efficiency. In 2018, 95% of its energy supply was imported (IEA, 2020). Even though Luxembourg’s renewable energy share is growing, low costs of energy coupled with the high purchasing power of its consumers presents a barrier that limits interest to invest in energy efficiency (see 4. Energy).

Fig. E.1: City Resilience Index Wheel (CRI) applied to Luxembourg (Arup)

- ***Import-Export dependency*** Among the European Member States, Luxembourg has the smallest number of agricultural holdings: 2’200 in 2010 (Eurostat, 2018), while land for agriculture and forest coverage makes 85% of total country land use (STATEC, 2018). The farm animal population decreased by 2.6% from in 2000 to 2010 (Eurostat, 2018). Agricultural raw materials and food imports represent 13% of total imports (World Development Indicators), which shows Luxembourg’s dependence on other countries, in lack of a self-sustainable food production chain. (see 5. Material flows, 6. Energy & 7. Agriculture)

- ***Insufficient waste management*** With 625 kg per capita, Luxembourg has one of the highest municipal waste generation rates in the EU, out of which only 50% is recycled. This paradigm is related to the small country size with its lack of physical space for treatment plants, which causes additional ‘out-source’ traffic flow. (see 5. Material flows)

Shocks

- ***Flooding & Climate Change*** Flood risk has historically been one of the highest natural risks in Luxembourg. Some regions have been devastated by floods several times: the Moselle valley in 1983 and the Sure valley in 1993, 1995, 2003 and 2011. The most recent flooding’s occurred after heavy rainfall in June 2018, hitting Greiveldange and Mullerthal and causing landslides, collapse of infrastructure and building damages

(RTL.lu, 2019). It is expected that the amplification of severe weather events by global warming will increase the magnitude and frequency of flood risk.

- ***Pandemic outbreak*** Due to the COVID-19 pandemic, STATEC expects Luxembourg's GDP to decline by 6% this year (Chronicle.lu, 2020). The government of Luxembourg has introduced a number of measures to support the economy by alleviating the financing and liquidity of Luxembourg companies. The temporary closure of the borders by France, Germany and Belgium, in an attempt to stop the spread of the virus, caused disruptions in food supply, as supply was cut off.

The CRI creates a framework of pillars and goals and allows to measure the impact of proposed strategies through an evidence-based approach.

How it works

The tool will be used to identify criticalities and opportunities through the four dimensions of CRI wheel, as illustrated in Figure d-1. The resilience of a city relates to four key dimensions:

- ***Health and wellbeing***: Systems that ensure the health and wellbeing of people living and working in the city.
- ***Economy and society***: The social and financial systems that enable urban populations to live peacefully, and act collectively.
- ***Infrastructure and Environment***: Built and natural systems that provide critical services, protect and connect urban citizens.
- ***Leadership and strategy***: The need for informed, inclusive, integrated and iterative decision making in our cities.

Underpinning the 4 Dimensions are 12 Goals that cities should strive towards in order to achieve resilience.

Goals are what matters most when a city faces a wide range of chronic problems or a sudden catastrophe. They range from how successfully a city provides from its residents' basic needs to ensuring inclusive economic participation, competency in infrastructure management to robust plans and strategies for the future.

52 Indicators add further definition to the 12 Goals. Indicators are a detailed array ranging from sanitation to availability of financing, crime prevention measures to continuity plans for critical assets. They are ***observable***, ***critical factors that contribute*** towards the resilience of urban systems.

Characteristics of resilience

Resilient systems have qualities that enable them to resist, respond and adapt more quickly to shocks and stress by taking appropriate or prompt action. A resilient system is cautious, concrete, rich in resources, redundant, flexible, inclusive, integrated and responds to following quality characteristics:

- ***Reflective systems*** accept the inherent and ever-increasing uncertainty and change in today's world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. An example of possible action for Luxembourg, can be the introduction of a specific plan of emergency response actions and monitor its updates and integrations over the years.
- ***Robust systems*** include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. In case of Luxembourg, monitoring the demand-offer balance of housing and construction can be introduced.
- ***Redundancy*** refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfill a particular function. A possible action for Luxembourg can be a set of powerful actions and strategies to become a self-sufficient in terms of both food production and supply.
- ***Flexibility*** implies that systems can change, evolve and adapt in response to changing circumstances. This may favor decentralized and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. Sample action for Luxembourg, may be a conversion of infrastructure from 'mono-purpose' to multi-functional by several users during different time periods and reduction of traffic congestion.
- ***Resourcefulness*** implies that people and institutions are able to find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilizing and coordinating wider human, financial and physical resources. In case of Luxembourg, energy and resources production can be shifted from import to in-loco, favoring also a reduction of C02 related to their transportation necessity.
- ***Inclusion*** emphasizes the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build resilience. An example of possible action for Luxembourg, can be to introduce communication campaigns/awareness events and teaching dedicated to the new sustainable behavior for all types of population – Luxembourgers and foreigners.
- ***Integration*** and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. In case of Luxembourg, the inclusive and participative decision-making can be implemented in order to guarantee the supportive mechanisms. As transnational economic and urban system Luxembourg needs transborder decision making as well. The missing of resilience in the transborder economic systems was exemplified with COVID-19.

The role of human behaviour - governance and learning zero carbon

The longer households in Luxembourg take to change their lifestyle and consumption patterns, the further the goal of climate neutrality will move into the future. "Technical solutions may be the main factor, but the gap between the GHG emission reductions that are technically possible and the actual ones becomes larger as technologies improve". For example, Switzerland could not achieve its GHG emission goals for 2020. One significant factor was a change of behaviour in the inverse direction in motorized individual transport. The gain of GHG emissions by better technologies in the car industry was partially lost again by producing and merchandising bigger and more powerful cars.

Changing to a zero-carbon way of life will be a question of supply and demand. Influencing the demand by establishing better or more attractive zero-carbon offers on one side needs to be supported by people's behaviour. If we assume that neither nuclear energy nor a repressive regulation («eco-dictatorship») is a desirable solution, it requires a large majority of the population to respect carbon reduction as a way of life.

How to increase consciousness in modern constitutional democracies will be one of the main topics of future governance and management of the climate crisis. With COVID-19, the old topic of managing restrictions moved back into the spotlight. In all cases – whether restrictive like in France and Spain or voluntary like in Switzerland and Sweden – any drastic political decision will have to be supported by a large majority of the population.

The following challenges have been identified for changing individual emission-related behaviour:

- ***Monitoring of individual carbon-footprint*** The first challenge is the creation of a database for emissions of households in different urban areas of Luxembourg. This is one of the most important indicators to observe the effect of different local strategies. The database could use the four following categories: housing, consumption, mobility and food. The development of a monitoring system on individual households' emissions should be considered as an evolutionary process during the first phase of decarbonization.

- ***Rethinking urban space*** The urbanization needs to develop stepwise densified urban structures, demonstrating a new quality of live by offering zero-carbon mobility, housing, feeding and consumptions in densified contexts in the city and transborder settlements.

- ***Learning zero-carbon*** Learning is an important factor. A learning and adaptive society is resilient and integrates change better into everyday life. There will be a need to install tools for knowledge exchange and physical opportunities to learn by doing in the everyday life. Learning by smart technologies or by individual and real contact with the environment should be considered as important challenge on the way to climate neutrality.

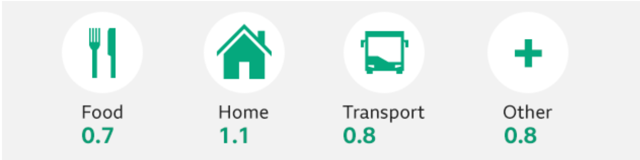


Fig. E.2: Annual consumption per person globally in tonnes of CO_2 equivalent (BBC, 20 May 2020)

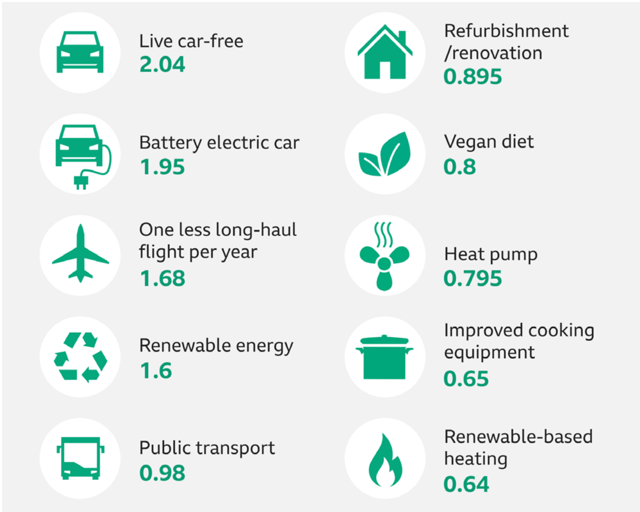


Fig. E.3: Top 10 options to reduce personal carbon footprint: Average reduction per person per year in tonnes of CO_2 equivalent (BBC, 20 May 2020)

III.

DOMAINS

1. Mobility

Summary

This section illustrates a wide set of interventions to tackle the different aspects in the mobility sector that contribute to the country's overall GHG emissions. The two measures below present opportunities with a significant GHG emission reduction potential, that can be introduced in a timely manner:

- ***Multimodal transport offer***: multimodal transport facilities will make the electrified railways a more attractive alternative and decrease the number of kms driven. This will catalyze a modal shift from car to public transport (M.S.7 & M.S.9).
- ***Pricing policies***: for personal car use, including road pricing, fuel taxations and parking cost. Introduction of pricing policies will increase the cost of driving facilitating a modal shift and reduce the impact of fuel tourism (M.S.4 & M.S.5).

These interventions could lead to a reduction of GHG emissions from road fuel between 55% and 85% (in a more aggressive scenario) in 2030, compared to 2005 figures. Similarly, the reduction in GHG emissions from personal vehicle usage in Luxembourg would range between 55% and 65% in 2030, compared to 2050. Further continuation of these policies would enable reducing combined GHG emissions from road fuel export and personal vehicle usage by 90% in 2050, compared to 2005.

Analysis

The transport and mobility sectors are the most significant contributors to the GHG emissions in Luxembourg. As of 2016, they accounted for almost 50% of the total share (Climate Watch, 2016). Some of the drivers are fuel tourism due to the low fuel taxation, the high number of company cars and the high level of cross-border commuting. These drivers result in high levels of car use within the country and correlate with the high number of cross-border workers, causing significant air pollution problems and traffic congestion at peak hours. Without proper interventions, these problems will continue to grow in the future, further aggravated by the predicted population growth.

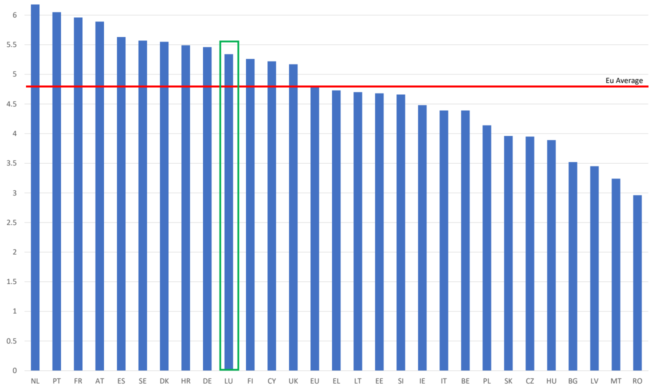


Fig. 1.1: Roadways quality in Luxembourg in the European Context

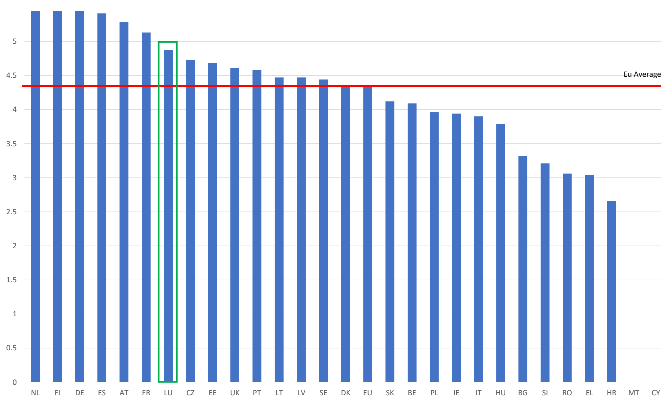


Fig. 1.2: Efficiency of train service in Luxembourg in the European context

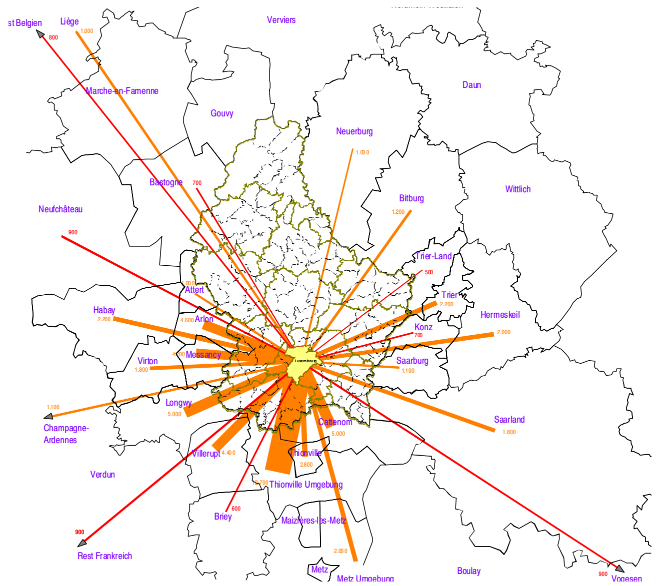


Fig. 1.3: Long distance traffic into and out of Luxembourg is common (Innenministerium, Transportministerium, Ministerium für öffentliche Bauten, Umweltministerium 2004)

As Luxembourg has one of the highest quality road infrastructure within the EU (European Commission, 2020), along with low transport fuel costs and parking policies which encourage car usage, the car is an appealing mode of transport, with a total of 83% share in the passenger transport modal split (a similar trend can be observed in freight transport where road-based transport makes up 88% of freight transport).

Luxembourg has one of the most efficient train services in the EU and the 3rd highest rail density in the world (European Commission, 2019). Multiple rail operators are working within the country such as CFL, SNCF (France), NMBS/SNCB (Belgium), and DB (Germany). Furthermore, 95% of the railway network in Luxemburg is electrified. Despite the high-quality rail infrastructure and services, the passenger transport modal split shows a clear preference for road transport over rail transport, which makes up just 5% of the modal split.

This low share of railways can be partially attributed to the convenience of car-based transport, and its ability to offer door-to-door trips. This is particularly important in the context of Luxembourg because there is a high concentration of businesses on the periphery of the urban centers. Additionally, many of the cross-border commuters come from locations that have no direct rail connection with Luxembourg such as the rural areas of Thionville and Villerupt.

As of 2017, electric cars made up 1.9% of the overall market share in Luxembourg, which was slightly above the EU average of 1.5%. Deployment of electric vehicle charging points was at 56,72 per 100.000 urban inhabitants in 2017, again slightly above the EU average 52,10.

Strategy and Methodology

Considering the mobility and transport characteristics of Luxembourg, the aim of the strategy is to tackle the main issues below:

- ***Car dominated modal split***, where the good road network and low cost of driving and parking encourages people to drive, rather than utilize public transport;
- ***Cross-border traffic***, attributed to the high level of housing prices, leading to a considerable amount of car commuters;
- ***Land use and public transport infrastructure***, there isn't enough level of coordination between the geographic distribution of workplaces and the public transport infrastructure, making the existing high service quality network inefficient for commuters.

Based on our analysis, an inventory of possible strategies is definied as follows:

- **M.S.1**. Utilisation of data to improve the transport system efficiency with focus on smart mobility, i.e. route and travel mode choice, among others
- **M.S.2.** Implement demand management measures to influence travel behaviour, e.g. remote working & coworking, and facilitating a modal shift from car to public transport
- **M.S.3.** Land use and public infrastructure alignment: densify areas surrounding public transport hubs and create transit-oriented business locations to maximise the use of the existing public transport infrastructure. As an example, the public transport accessibility level (PTAL) system in the United Kingdom could be employed here
- **M.S.4.** Evaluate and update existing policies to increase the total cost of personal car use (fuel, tax, parking, etc.)
- **M.S.5.** Introduce road pricing tools to execute polluter pays policy for cars
- **M.S.6.** Push for alternative transport fuels;
- **M.S.7.** Promote sustainable travel and design for increased synergies between public transport and cycling; shared mobility; the 15-min city; encouraging off-peak travel

- **M.S.8.** Infrastructure changes and upgrade of PT service in rural areas
- **M.S.9.** P&R and sharing offers at the border

Key Metrics

The set of key metrics suggested in this section presents a pathway to mobility decarbonization in Luxembourg. By monitoring each of these variables, the effectiveness of new measures can be determined, and the overall progress of the strategy can be measured:

- **M.KM.1.** Car ownership per household in number of cars/households
- **M.KM.2.** People working from home in the passenger transport modal split in %
- **M.KM.3.** Car cost of travel and parking in Euros
- **M.KM.4.** Public transport versus Car accessibility to the next urban area using Trip Time Ratio indicator
- **M.KM.5.** Share of public transport, long distance railways and buses in the passenger transport modal split in %
- **M.KM.6.** Average commuting car distance for cross-border traffic in kilometers
- **M.KM.7.** The proximity of workplaces to public infrastructure represented as travel time
- **M.KM.8.** Multimodal transport facilities usage degree against number of people driving (Mobility hubs, Park+Ride, Bike+Ride, Demand Responsive Transport, etc.)
- **M.KM.9.** Number of car-sharing stations, station coverage and usage degree in %
- **M.KM.10.** Quantity of public transport stops with bicycle parking
- **M.KM.11.** Share of renewable energy in transport fuel consumption in %
- **M.KM.12.** Market share of electric and hydrogen vehicles in %
- **M.KM.13.** Quantity of Electric Vehicles charging points / Hydrogen stations and its network coverage in driving time

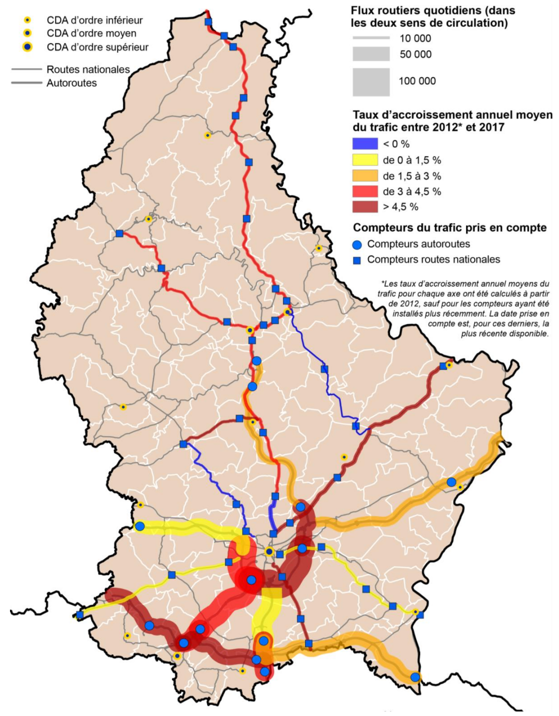


Fig. 1.4: In terms of commuter dynamics, mostly people travel to and from Luxemburg from the south west region and all the way to France and Belgium. (Deconville and Feltgen, 2018)

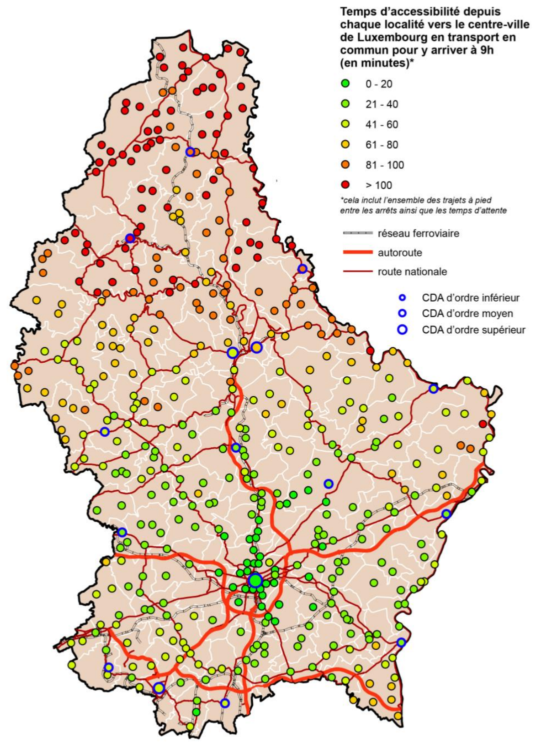


Fig. 1.5: Public transport services from the localities are excellent, almost all of which are connected to the capital. (Deconville and Feltgen, 2018).

2. Logistics

Summary

Similar to the mobility sector, freight transport and logistics are significant contributors to Luxembourg's GHG emissions. The following interventions can be implemented in a timely manner and offer the most significant potential in reducing GHG emissions:

- ***Pricing policies for road-based logistics***: increase the cost of driving, thereby facilitating a modal shift to railway and inland waterway transport, and reducing the impact of Fuel Tourism (L.S.3).
- ***Electrical or hydrogen-based trucking:*** Policy and infrastructure development to facilitate electrical and hydrogen-based trucking, providing a clean alternative for road-based transport (L.S.4).

These interventions will lead to GHG emission reductions from road fuel for logistics vehicles between 55% and 85% (in a more aggressive scenario) in 2030, compared to 2005 figures. Similarly, GHG emission reductions from freight transport vehicles could range between 30% and 55%, compared to 2005. Further continuation of this policy would enable to reduce the combined share of GHG emissions from road-based freight transport by 90% in 2050, compared to 2005.

Analysis

Similar to the mobility sector, freight transport and logistics are also significant contributors to the country's GHG emissions. According to Climate Watch (2016), aviation and shipping counts for around 13% of the total GHG emissions. Freight transport and logistics are one of the most important economic pillars in Luxembourg, with a considerable share of the total European freight transport. This is a growing sector where Luxembourg is consistently within the top 25 countries in the world based on the Logistics Performance Index (LPI), ranking as high as 2nd place in 2016 (Benelux Union, 2016).

Luxembourg, along with other countries in

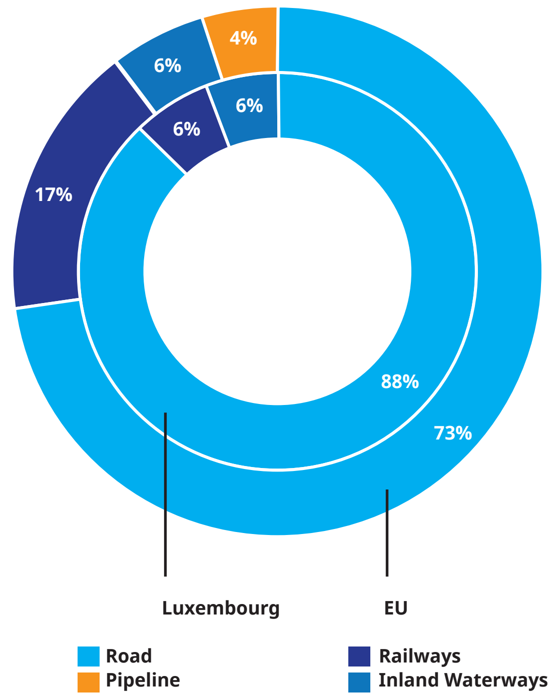


Fig. 2.1: Road-based freight transport is the dominant mode in the logistics sector in Luxembourg. Luxembourg has also a considerable share of inland waterways (European Commission, 2019)

the Benelux region, is functioning as a logistic hub serving mainly other countries in the region. Luxembourg and the Benelux region play an important role for France's and Germany's freight and logistics transport, where a considerable amount of France and Germany freights are transported through the Benelux region (Benelux Union, 2016).

Freight transport and logistics play a crucial role in the context of Luxemburg, considering the good-quality roadways, low fuel taxation, and lower cost of freight road-based transport. This also attracts external freight transport, adding more pressure on the existing network and contributing to the high emissions figures. Road-based freight dominates the modal split, with an 88% share, with a roughly similar share for railways and inland waterways of roughly 6%.

Considering the economic importance of the freight and logistics sector, and its environmental impact represented in traffic on roads, this represents an interesting challenge in balancing economic benefit against 'foreign pollution' and the need to look at logistics

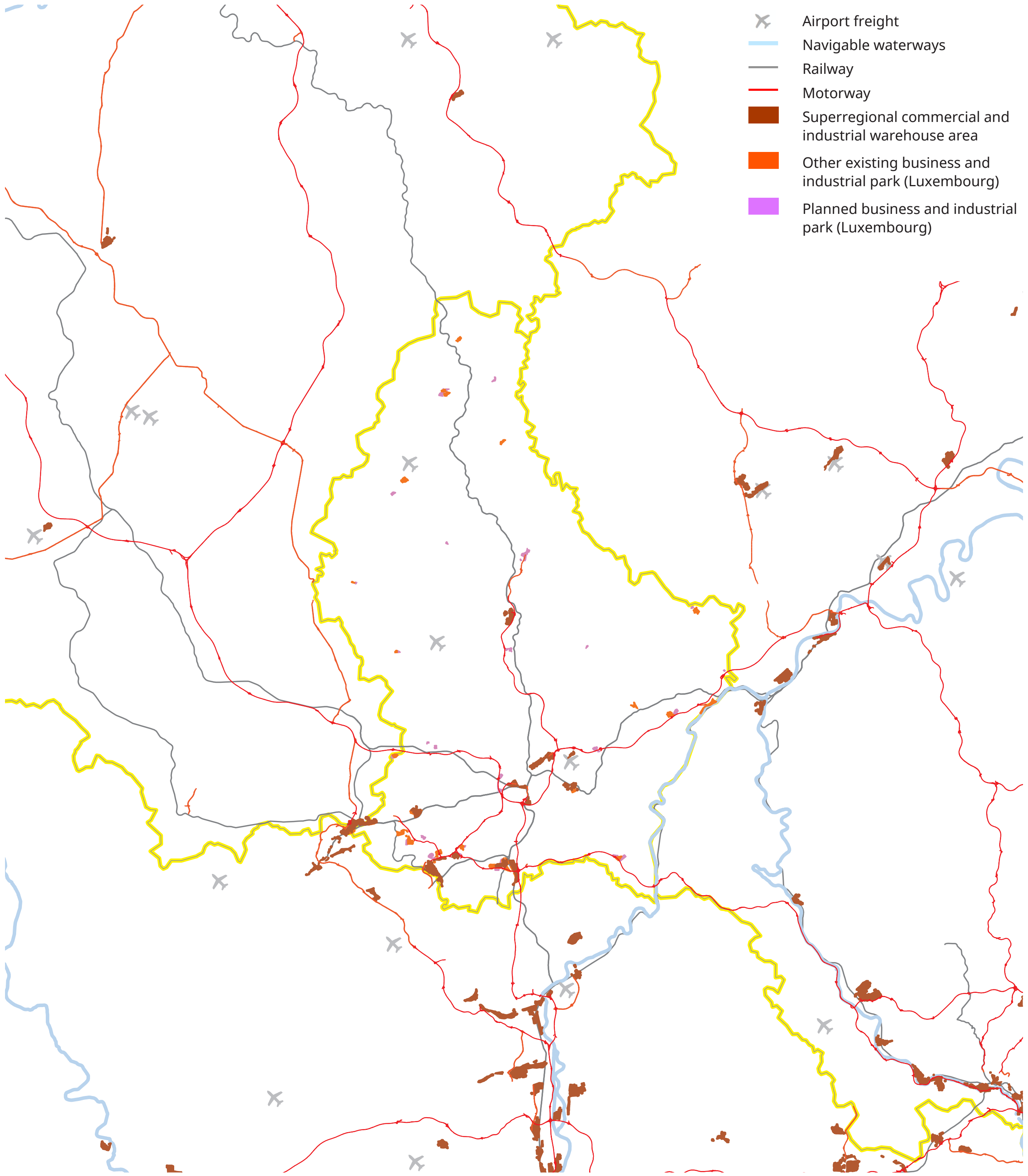


Fig. 2.2: Regional logistics infrastructure (KCAP, based on data from Geoportal and Open Street Map)

within the context of the transnational region. The transnational character of the logistics sector also requires constant review of and alignment with European developments, as they can greatly influence existing business models. One example is the "modal shift", which was announced as part of the European Green Deal in an effort to lower emissions from inland transport. Its aim is to increase the share of rail and inland waterway transport and reduce the share of road transport. To keep Luxembourg's position as a logistics hub requires a strong vision and roadmap for the expansion of rail and inland waterway transport capacity.

Air freight also plays an important role. Luxembourg Cargocenter is the 7th largest airfreight platform in Europe and the 25th largest in the world in 2018 (Eurostat, 2020). CargoLux, the country's main carrier, connects the country with all continents in the world and other EU Countries. In terms of air freight, in addition to the employment of technological advances to reduce greenhouse gas, it is important to adopt policies that aim to reduce GHG such as EU Flightpath 2050 and Single European Sky reform. These policies are designed to address the climate impact of aviation and work towards a cleaner aviation sector, meeting both market needs as well as maintaining responsible global leadership.

Strategy & Methodology

Based on our analysis, an inventory of possible improvements strategies is defined as follows:

- **L.S.1.** Propose balancing the economic benefit against 'foreign pollution' by increasing pricing
- **L.S.2.** Concentrate and reorganize collective logistic buildings and clusters, aligned with the rail- and waterway infrastructure.
- **L.S.3.** Promote pricing policies for
- road-based logistics
- **L.S.4.** Develop policies and infrastructure to advance electrical or hydrogen-based road transport.

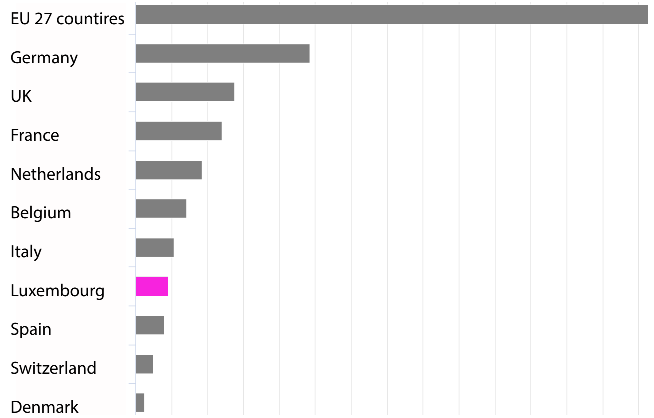


Fig. 2.3: Luxembourg located within the top 10 countries in EU in terms of freight and mail air transport (Eurostat, 2018)

- **L.S.5.** Push for rail and air-terminal, automated and underground transport, transit share, last mile urban logistics/delivery/storage logistics
- **L.S.6.** Adapt policies and upgrade infrastructure to facilitate modal shift from road-based transport to waterways and railways
- **L.S.7.** Develop a roadmap for sustainable aviation, starting with Single European Sky reform, that will help to cut up to 10% the air transport emissions

Key Metrics

The following list contains relevant metrics to track the decarbonisation progress to asses success of strategy:

- **L.KM.1.** Driving cost of travel and parking in Euro/Ton/Kms
- **L.KM.2.** Share of railways and waterways in the freight transport modal split in %
- **L.KM.3.** Average kilometres travelled within Luxembourg in per vehicle
- **L.KM.4.** Proximity of logistic hubs to railways and waterways infrastructure
- **L.KM.5.** Share of renewable energy in transport fuel consumption in %
- **L.KM.6.** Market share of electric and hydrogen vehicles in the freight transport in %
- **L.KM.7.** Number and network coverage of electric charging points and hydrogen stations for logistics

3. Buildings

Summary

As platform of the residents' daily activities, the building stock's reduction in GHG emissions reflects the development of the sustainable behavior of the society. As sustainable construction and materials are well integrated in Luxembourg's current legislation, the most effective measures lie with the existing building stock and new typologies:

- ***Stimulate renovation and retrofit***: to allow higher energy efficiencies and use of sustainable energy sources and materials in the existing building stock (B.S.2 & B.S.8).
- ***Create compact mixed-use typologies*** to be constructed around centralities: for a higher efficiency in infrastructures and land use (B.S.6).

Both measures are time- and cash-consuming. Thus the goal for GHG emissions reduction in residential buildings is set between 40-50% for 2030, while for commercial and institutional buildings the goal is around 67%, because these are easier to influence via regulatory and monetory incentives. During this period, technological development and price reduction for sustainable techniques will have evolved, so that an acceleration in renovation and retrofit in the next stage till 2050 can be expected.

Analysis

The building sector is the second largest contributor to GHG emissions in Luxembourg. With 1.8 million tons of CO_2 equivalents, it accounted for 17% of the total emissions in 2018, (MECS, 2020). Due to the low energy prices and low renovation rate of the existing building stock, both residential and non-residential buildings' energy consumption have been significantly higher than the EU average (EC, 2016).

Single-family dwellings as a major GHG emitter

Constituting 67% of the total building stock, residential space in Luxembourg was around 30 million m² in 2015, of which 71 % were

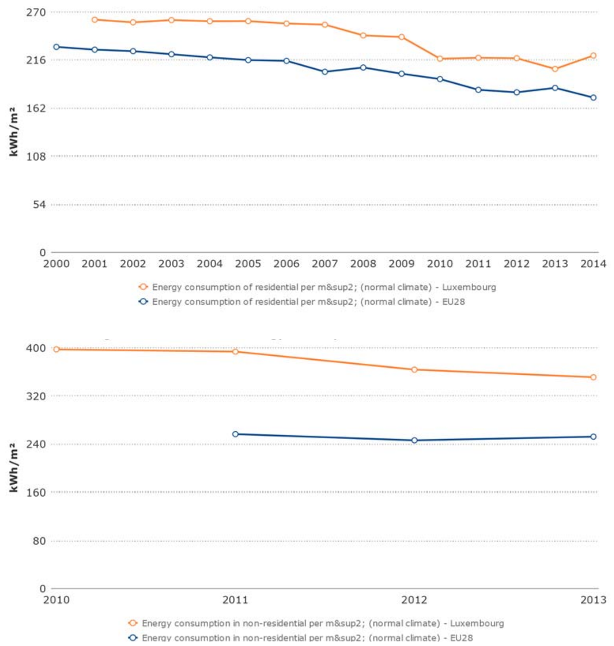


Fig. 3.1: Residential and Non-Residential energy consumption at normal climate (all end-uses), Luxembourg vs. EU 28 (EC, 2016)

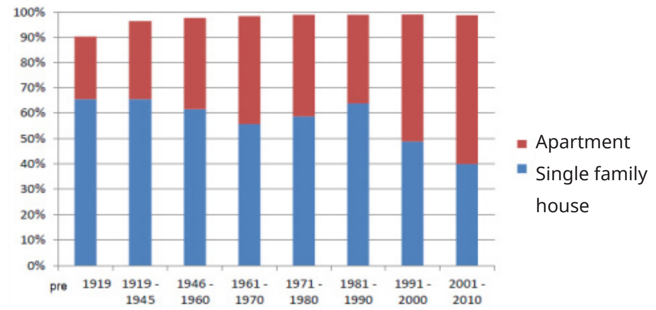


Fig. 3.2: Percentage of single family houses and apartment blocks constructed in different time period (ME, 2017)

single-family houses (including semi-detached and terraced houses). After 1995, the proportion of apartment blocks became greater in newly constructed plots, while the demand for single family units decreased slowly. For example, single-family houses still accounted for 36% of the total new residential units in 2017. Hence, they are still dominating in the residential building stock.

Older non-renovated and non-isolated buildings with outdated heating and cooling systems tend to burn lots of fossil fuel. In terms of heating type, single family houses' dependency on heating oil (56.3%) is much higher than that of apartment buildings (28.6%), which use more natural gas. In addition, the average living space per single-family house (175 m² for all building age groups) is significantly higher than the space per unit in a multi-family apartment building (83 m²) (MESD, 2020), They also tend to be more remotely located and dependent on access by car. Hence, they have the biggest share in CO_2 emissions within the entire building stock.

Challenges in renovating existing building stock

Considering the expected strong population growth, the total living space is estimated to increase from 34 million m² (2020) to around 57 million m² by 2050 (Ploss, 2018). The share of low energy-efficient building stock built before 2010 may account to ca. 45%, which is similar to non-residential buildings. Hence, energy-efficient renovation of the existing building stock is urgent. However, although Luxembourg initiated a nearly zero-energy building-policy a decade ago (MEIT, 2010), the energy renovation rate (average 2012-2016) was still as low as 7.1% in Luxembourg, in comparison to the EU average of 12.3%, or the worst in EU (EC. 2019).

In order to speed up energy efficiency, Luxembourg released the Enhanced Building Renovation (EBR) Strategy in 2017, aiming to increase the rate and quality of renovations. Regular updates of the energy efficiency standard are planned to reduce consumption and increase the use of renewable energy. This has resulted in a gradual improvement during the last years, for instance by introducing wood as heating fuel (MECS, 2020).

Strategies & Methodologies

- **B.S.1.** Promote construction with sustainable,renewable materials like wood and discourage the use of cement and high-temperature steel. Create a vision for flexible and reversible buildings
- **B.S.2.** Accelerate renovation/replacement of existing buildings with strong policy/ legislation on sustainable energy usage in buildings.
- **B.S.3.** Investigate the potential for district infrastructure in central locations
- **B.S.4.** Develop a scenario for the need for new buildings in relation to the expected population growth, household size, building typology and use-mix, taking into account new trends like home-office and co-working. This includes a shift from single houses to compact apartment buildings – due to price and life-style changes and transnational context.
- **B.S.5.** Promote construction in (brownstone) areas in centralities near public transport stops.
- **B.S.6.** Promote sustainable energy sources for heating and cooling of buildings, which is linked with energy and material supply.

Fig. 3.3: Renovation needs standards & cash (https://energymonitor.ai/)

Fig. 3.4: Energy-plus-school made of wood (https://structurae.net/)

Key Metrics

- **B.KM.1.** Energy efficiency
- **B.KM.2.** Energy source (district infrastructure, heatpumps, wood, solar)
- **B.KM.3.** Renovation potential
- **B.KM.4.** Tax for bad energy performance
- B.KM.5. Floor surface to volume proportion to measure compactness
- **B.KM.6.** Mixed use typologies
- **B.KM.7.** 24 h balance in energy usage
- **B.KM.8.** Sustainable and renewable materials.

4. Built footprint / Land occupation

Summary

The land use condition is essentially related to all the other domains' GHG emission reduction potentials. Some measures mentioned in previous domains are directly about land occupation, expecially those for transport (mobility and logistics) and building stocks. Priority measurements with a high impact on GHG emissions mitigation are:

- ***Land use and public infrastructure alignment*** to promote compact development around centralities with corresponding densities (LO.S.3).
- ***Create a comprehensive "Richtplan"***, a binding central Zoning Plan for Luxembourg with mandatory zones of built and non-built, making use of «breaking factors» (LO.S.2.) to prevent urban sprawl and avoid damaging greenfield development.

These measures will set up the framework for Luxembourg's future development to accomondate the increasing population, spatially guide construction and renovation activities, as well as the recovery of ecosystems. Provided these policies are strickly implemented, they will significantly contribute to other domains' efforts towards the achievement of their GHG emission goals, expecially in longterm towards 2050.

Analysis

Luxembourg is now experiencing unprecedented demographic growth. From 2000 to 2018, the population grew with 40%, and there was a 45% increase in daily cross-border commuters coming from neighbouring regions of France, Germany and Belgium. This boosted the real estate market and accelerated land conversion. Of the total area of 2,586 km² in 2018, about 274 km² (10.6%) was occupied by human settlements (EEA, 2019a). During the period 2000-2018, the country kept converting significant amounts of land into urban areas, more than any other European countries (except the Netherlands), at a yearly land take rate of 313.2 m²/km². Although the

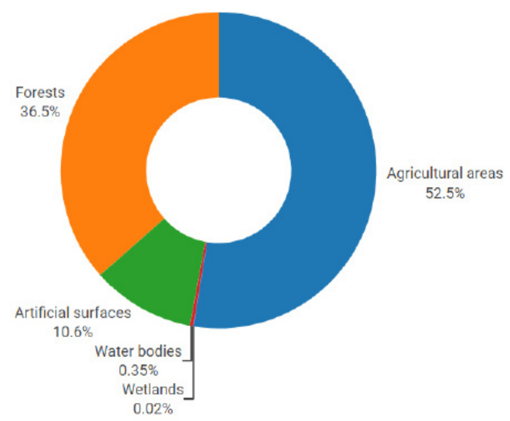


Fig. 4.1: Structure of the lanc dover area in Luxembourg 2018 (FISE, 2020)

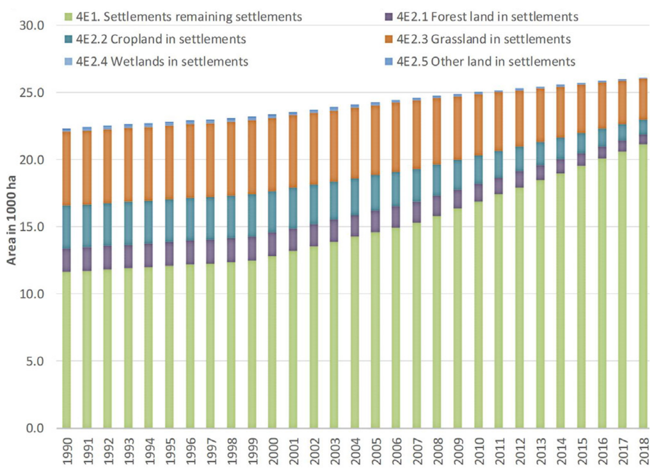


Fig. 4.2: Conversion of other land use into settlement from 1990 to 2018 (MECS, 2020)

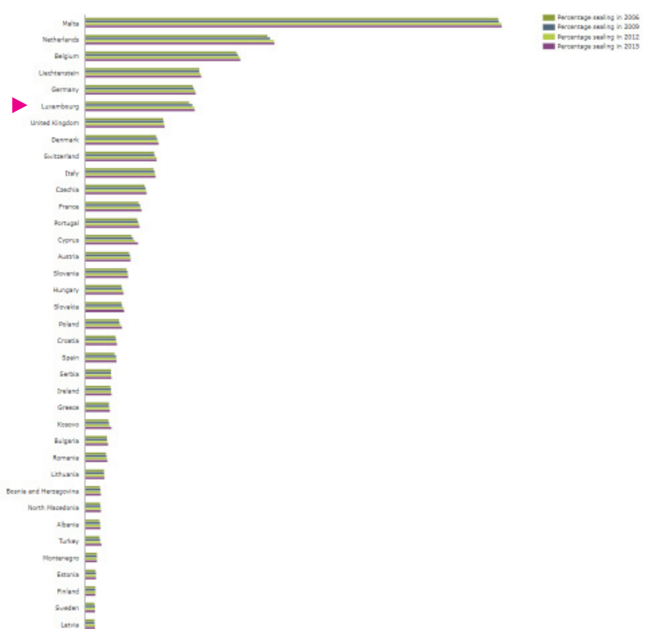


Fig. 4.3: Comparison of EU counrties in terms of soil sealing (2006-2015) (EEA, 2019c)

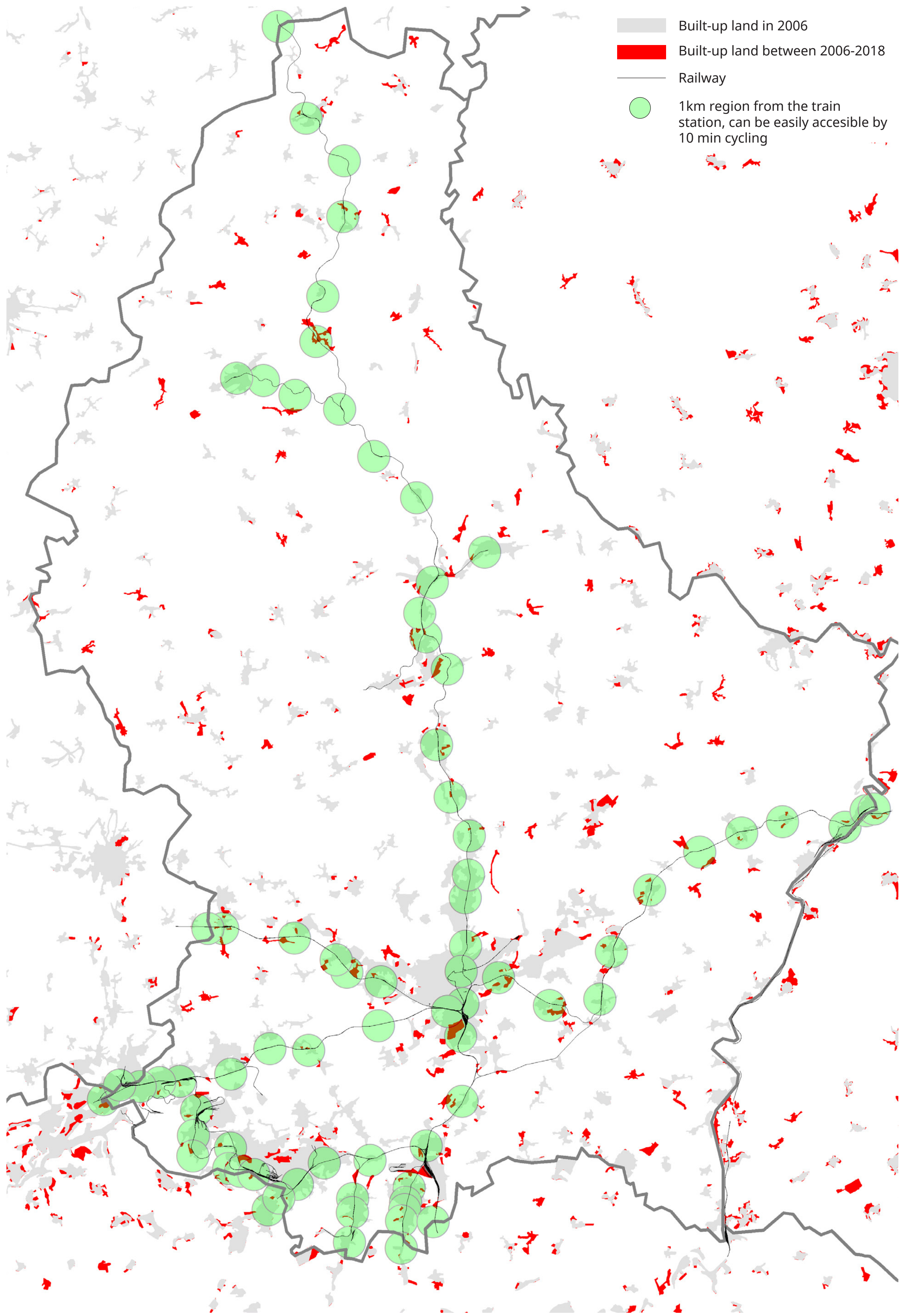


Fig. 4.4: Urban growth (2006-2018) with low relationship with public transportation accessibility (KCAP, based on data from Geoportal)

rate of sealed surfaces per capita dropped from 605 m^2 (2000) to 453 m^2 (2018) due to the proliferation of more compact development typologies, it still belongs to the highest in Europe (e.g. 321 m^2 in the Netherlands and 330 m^2 in Switzerland).

Uncontrolled sprawl in rural communities

In the past two decades, the government has tried to control urban growth in the country (MISD, 2004). Spatial development concepts such as 'Decentralised Concentration' or 'Development and Attraction Centres' (Feist, 2020)to limit the number of centralities and settlements have been made for a long time. However, due to the decentralised planning culture, based in the municipalities, the reality is an uncontrolled housing boom in rural communities (Feist, 2020). This also has to do with land-prices, which are considerably lower outside the agglomeration. The result is a sprawled condition, which stimulates automotive traffic at the cost of public transport.

Hence, land conversion constraint in non-urban region and densification of the existing sealed surface is crucial for Luxembourg's low-carbon development in the future. In this fast growing country, without strict measurements to facilitate compact, public transportation driven development pattern, a low-carbon society will hardly be possible.

Strategy & Methodology

- **LO.S.1.** Calculate probable requirement of total constructed floor space / total built and sealed surface, when the population grows from 650.000 to 1.100.000. Then Estimate the potential and distribution of redevelopment and densification extrapolated from current economic growth' spatial factors. Priotize landuse in centralities.
- **LO.S.2.** Identify and exploit the "braking factors" against over-urbanisation (e.g. property lines, forest zones, state defined minimal cropland surface, water protection areas, topography, natural reservations, noise and nuisance legislation, distance rules, listed urban ensembles, zoning plans, etc.).
- **LO.S.3.** Avoid greenfield development and promote brownstone development. Identify potential brownstone construction sites. Calculate their capacity potential of built footprint and floor space, depending on typology, function, density principles; preferably near public transit and centrality nodes. Compare the resulting figures with the need for built surface (differentiated in functions) . Ensure minimal new land take.
- **LO.S.4.** Where greenfield development is unavoidable, indicate what compensation mechanisms could be deployed.
- **LO.S.5.** Create spatial scenarios and visions how to allocate future development in an integrated way in the Luxembourg urbanized landscape, integrated with mobility, centralities, transnational condition, in short the other variables in this proposal.
- **LO.S.6.** Review planning authority hierarchy between state and communes. Check planning and policy instruments on impact in the above processes. Then optimize the spatial planning policy.

to \ from	Forest land	Annual Cropland	Perennial Cropland	Grassland
Forest land	0	-1.784	-1.237	-0.476
Annual Cropland	1.784	0	0.462	1.308
Perennial Cropland	1.237	-0.462	0	1.517
Grassland	0.476	-1.308	-1.517	0
Settlement	3.393	1.609	1.616	2.917

Fig. 4.5: Land use change matrix for soil carbon emission factors (tC/ha*y) (MECS 2020)

Key Metrics

- **LO.KM.1.** Zoning for densification
- **LO.KM.2.** Zoning for urban renewal
- **LO.KM.3.** Zoning for re-cultivation
- **LO.KM.4.** Zoning for construction constraint
- **LO.KM.5.** Access to public transport
- **LO.KM.6.** Occupation density
- **LO.KM.7.** Extent in mixed use
- **LO.KM.8.** Forest and cropland reserve
- **LO.KM.9.** Biotope protection zone
- **LO.KM.10.** Topography
- **LO.KM.11.** Water protection zone
- **LO.KM.12.** Noise and nuisance zone

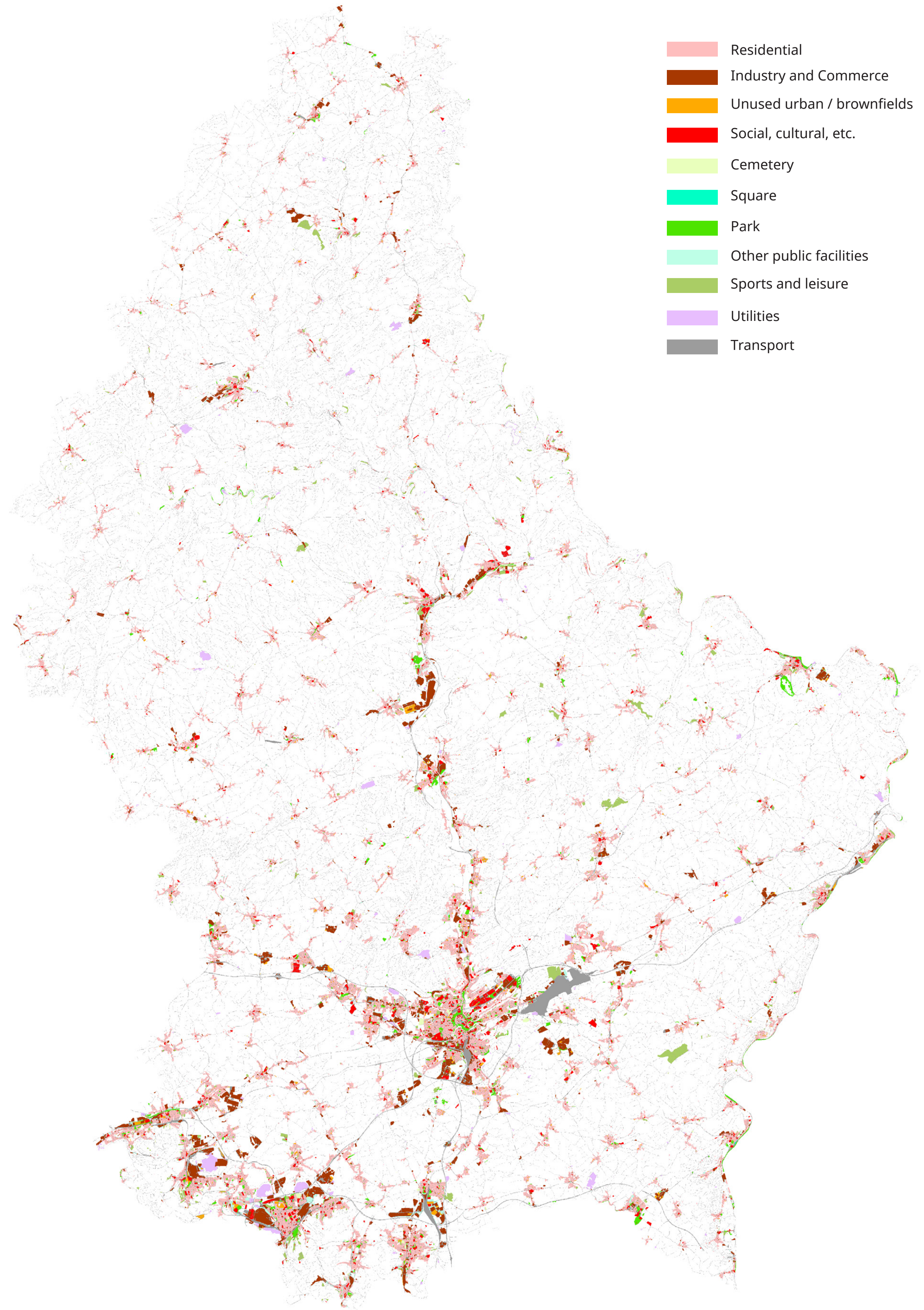


Fig. 4.6: Map of settlement landuse (KCAP, based on data from Geoportal)

5. Material Flows

Summary

Despite the modest contribution of waste and material flows to the overall GHG emissions, measures could still be prioritised to achieve gains in this sector. The priority areas of attention to achieve the most impact in the first period to 2030 are:

- ***Awareness***: Creating awareness campaigns that highlight to local and cross border populations the responsibilities associated to consumption (MF.S.7).
- ***Construction Sector***: strengthen policies to tackle waste in the construction sector. (MF.S.3).
- ***Landfill pricing***: introduce more appropriate forms of pricing measures to manage landfill less attractive (in favour of more GHG friendly forms of land-use) (MF.S.5).

These measures could have as target to contribute to Luxembourg achieving a reduction by 55% of GHG emissions associated to waste by 2030 (compared to 2005). At that point, the introduction of a broader range of strategies (as described above) will collectively contribute to the overall ambition of 90% reduction by 2050.

Analysis

In terms of greenhouse gas emissions, waste management in Luxembourg exhibits a continuous decrease over the years. In 2017, it accounted for approximately 84 thousand tons of CO_2 equivalent - or 0,83% of the total emissions share from this year. (Statista, 2020; Statistiques Grand-Duché de Luxembourg, 2020a, 2020b; Eurostat, 2020d;). While a great share of these emissions is either reabsorbed or treated (European Environment Agency, 2013), it is necessary for a policy that requires the reduction of waste quantities produced within a clearer and stronger framework – recently, efforts towards this were framed within the PNGD Plan and the Climate Pact of the country. (European Union, n.a.).

With 625 kg per capita, Luxembourg has one

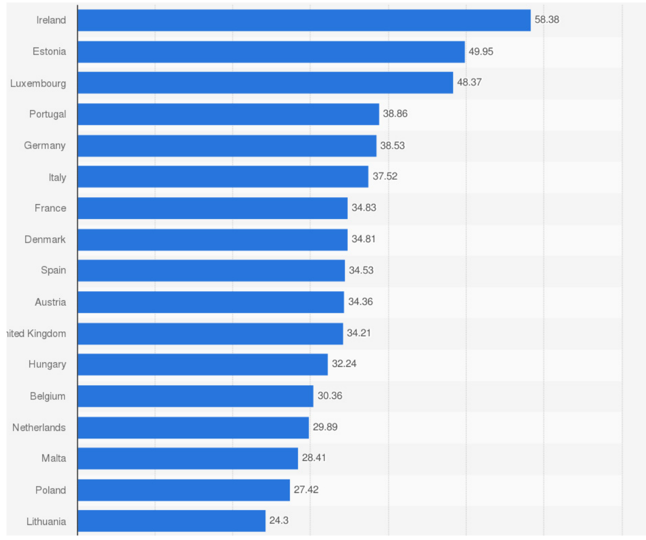


Fig. 5.1: Generation of plastic packaging per capita in EU 2017

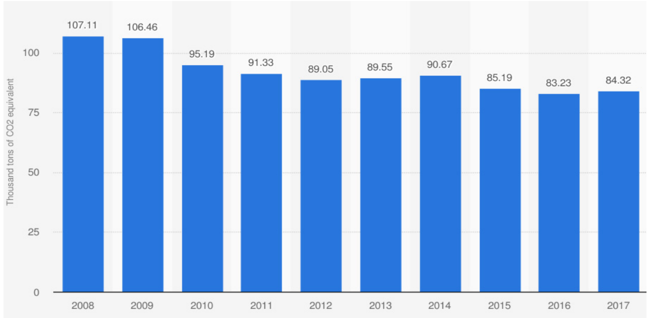


Fig. 5.2: Annual greenhouse gas emissions from waste management in Luxembourg from 2008 to 2017

of the highest municipal waste generation rates per inhabitant within the European countries (Eurostat, 2020a). The behavior of the population clearly affects consumption patterns. Luxembourgers deemed themselves as extremely focused on consumption and, as of 2019, approximately 30% of the local population was hesitant with regards to the reuse of products. (Ipsos, 2019). Moreover, waste generation figures are highly influenced by behavior patterns from cross-border commuters (PNGD, 2018).

In terms of waste treatment, the country has shown continuous improvement with regards to its municipal waste recycling rates. In 2018 approximately 50% of its municipal waste was recycled. (Eurostat, 2020b) and this is currently well above the European rate (European Environmental Agency, n.a.). In terms of packaging recycling – and specially in terms of plastic packaging, there is still room for improvement, as rates are below of the stated goals and one of the highest per inhabitants within Europe. (European Environmental Agency, n.a.; European Parliament, 2018; Statistiques.public.lu, 2020b).

It should be noted that Luxembourg has one of the lowest landfill taxes within the European countries. (CEWEP, 2020; Statista, 2020a). As of 2017, 6,91% of municipal waste is destined to landfills (an improvement if compared to 17% in 2006) (European Environment Agency, 2019), which still contributes to the Greenhouse Gas Emissions in the country through the emission of landfill gas. Landfilling is arguably relatively cheap, and the country is running out of space in its landfills to manage the upcoming quantities of waste, specially from the construction sector. (Reporter, 2020; Luxemburger Wort, 2016). Studies report the south west and central regions as areas that deserve special attention due to exceeded landfilling capacity. (MDDI, n.a.).

It is also important to note that while a considerable share of hazardous waste is used for energy recovery or for recycling and backfilling (European Environment Agency, 2020), shipments of this type of waste have been increasing over the years – an increase of almost 400% between 2001 and 2018 (Eurostat, 2020c). As of 2016, Luxembourg had the highest rate of hazardous waste per capita within the EU-28 (Eurostat, 2020c).

Luxembourg exports more waste than it imports. Statistics show that the biggest share of exports go to France, followed by Germany (Statistiques.public.lu, 2020c). This ratio points towards the necessity of increasing Luxembourg's resilience by making it more independent from external factors (EPEA, 2015). Mineral waste accounts for the biggest share of the stream for the total generated waste in the construction sector. Furthermore, Luxembourg has one of the highest constructions and demolition waste per capita in Europe, where a high percentage is recovered (approximately 90%). However, this is not on a par with the total amount of construction waste

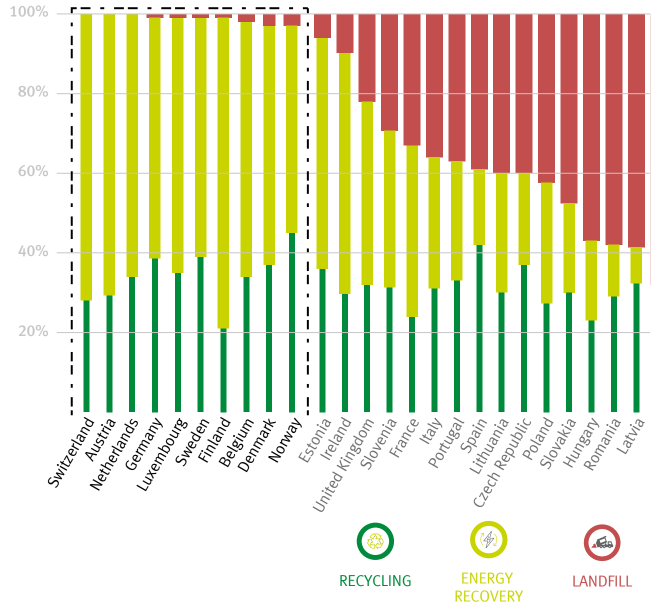


Fig. 5.3: Plastic post-consumer waste rates of recycling, energy recovery and landfill per country in 2018

generated (European Commission, 2017).

With a continuous population growth and a rising urbanization rate (Statista, 2020c), and with the growth of cross-border employment coupled with dependency factors caused by increasing imports' rate, the implementation of circular economy policies with special focus on population education, municipal waste generation, management of construction waste and raising the country's resilience towards externalities poses great potential for the better use of resources and to decrease Luxembourg's ecological footprint. (European Environment Agency, 2015).

Arguably, CO_2 that is emitted into the atmosphere must also be considered as a waste product. Therefore, the development of a CO_2 transport and storage infrastructure should be evaluated, to enable emitters of CO_2 to install carbon capture processes. In the short term, this enables processes that do not have emission-free alternatives yet, like waste incinerators or cement producers, to quickly reduce their emissions without having to stop operating. It also enables net-negative emissions if CO_2 is captured from biomass-fired power plants, as trees remove CO_2 from the atmosphere. The captured CO_2 can either be transported to a permanent storage location, or be reused, e.g. for the production of chemical feedstock.

Strategy & Methodology

After carefully evaluating the possible changes within this sector, the team synthetized the most relevant in the following list:

- **MF.S.1** Apply the principles of waste generation prevention, followed by revaluation, and repurpose, as stated by the PNGD Plan, particularly when it comes to household and construction sectors (PNGD, 2018)
- **MF.S.2** Reduce the externalities related to Luxembourg's waste with the aid of circular economy principles and urban mining
- **MF.S.3** Apply principles of urban mining to the construction sector and analyse the potential of reducing landfilling and increasing recycling rates of building stocks
- **MF.S.4** Analyze possible synergies between waste disposal and land use for suitability of Carbon Capture and Storage (CCS). Instead of using limited land for landfill sites, waste can be incinerated and the resulting CO_2 can be captured for reuse or permanent storage
- **MF.S.5** Increase landfilling tax
- **MF.S.6** Repurpose of the large-scale landfills for inert waste and demolition waste treatment facilities within the framework of the Circular Economy Directive of the European Union, with focus on conflict areas, i.e. southwest and center regions
- **MF.S.7** Create awareness campaigns among local and cross-border population with regards to consumption and recycling
- **MF.S.8** Implement full scale recycling and energy recovery, transnational coordination, sustainable materials in the construction sector.

Key Metrics

- **MF.KM.1** Quantity of municipal waste generation in kg/capita/year
- **MF.KM.2** Quantity of waste destined to landfills in t/capita/year
- **MF.KM.3** Recycling share% of municipal waste
- **MF.KM.4** Recycling rate of plastic waste in %
- **MF.KM.5** Rate of municipal waste treated for energy generation in %
- **MF.KM.6** Quantity of inert waste in t per year
- **MF.KM.7** Quantity of waste exports in t per year
- **MF.KM.8** Quantity of steel and
- aluminum from recycled sources in t/year
- **MF.KM.9** Quantity of construction
- demolition waste generated in t/year
- **MF.KM.10** Quantity of construction demolition waste reinserted in the stream in t/capita/year
- **MF.KM.11** Quantity of raw material imported in t/year
- **MF.KM.12** Quantity of plastic packaging waste in kg/capita/year
- **MF.KM.13** Amount and location of EU ETS installations (large stationary emitters of CO_2)

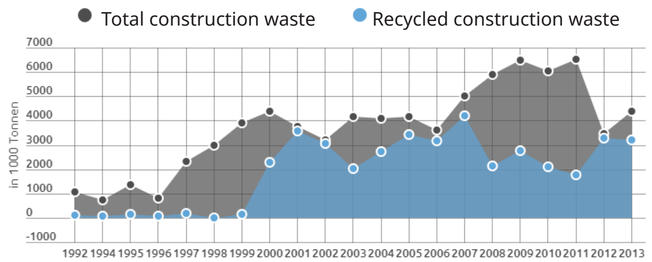


Fig. 5.4: Capacity and recycling of construction waste landfills in Luxembourg (Umweltverwaltung, wort.lu).

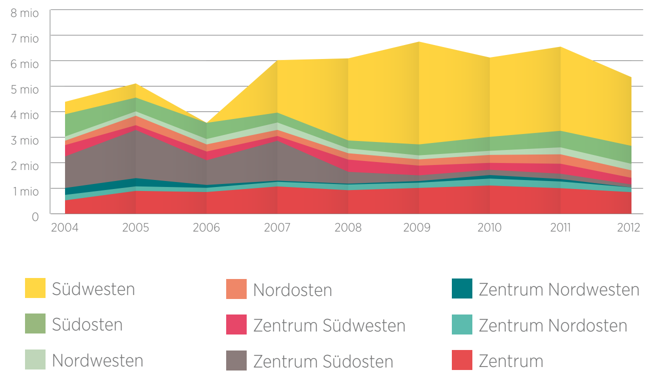


Fig. 5.4: Excavation volume per region. (Ministère du Développment durable et des Infrastructures, n.a.).

6. Energy

Summary

Measures to tackle GHG emissions relating to energy consumption have been listed in the previous domains (e.g. developing policies for high consuming energy typologies, increasing fossil fuel prices). However, besides changing consumption, Luxembourg should implement strategies and methodologies to reduce GHG emissions associated to energy supply. Key measures to achieve the most impact in the 1st phase till 2030 are:

- ***Renewable energy infrastructure***: Continue the ongoing plans to support local renewable power generation (E.S.1).
- ***Increase inland renewable electricity generation***: Domestic electricity generation should be pushed by including end-users in the electricity grid as producers. A positive consequence would be a decrease of Luxembourg's energy dependence (E.S.3).

If thoroughly implemented, Luxembourg's target of domestic electrical production of 30.3% by 2030 (IAE, 2020) is achievable. And till 2050 the electrical energy import can be reduced to 0 and substituted by renewable production accounts for ca. 22% of the nation's total energy supply, with similarly significant mitigation in GHG emissions.

Analysis

With approximately 8.7 million tons of CO_2 equivalents (Statista, 2020), the energy sector accounted for approximately 72% of the total emissions in 2017 (Eurostat, 2020). It is important to note that these emissions are also reflected in other sectors and that the absolute share of this domain is therefore hyperinflated.

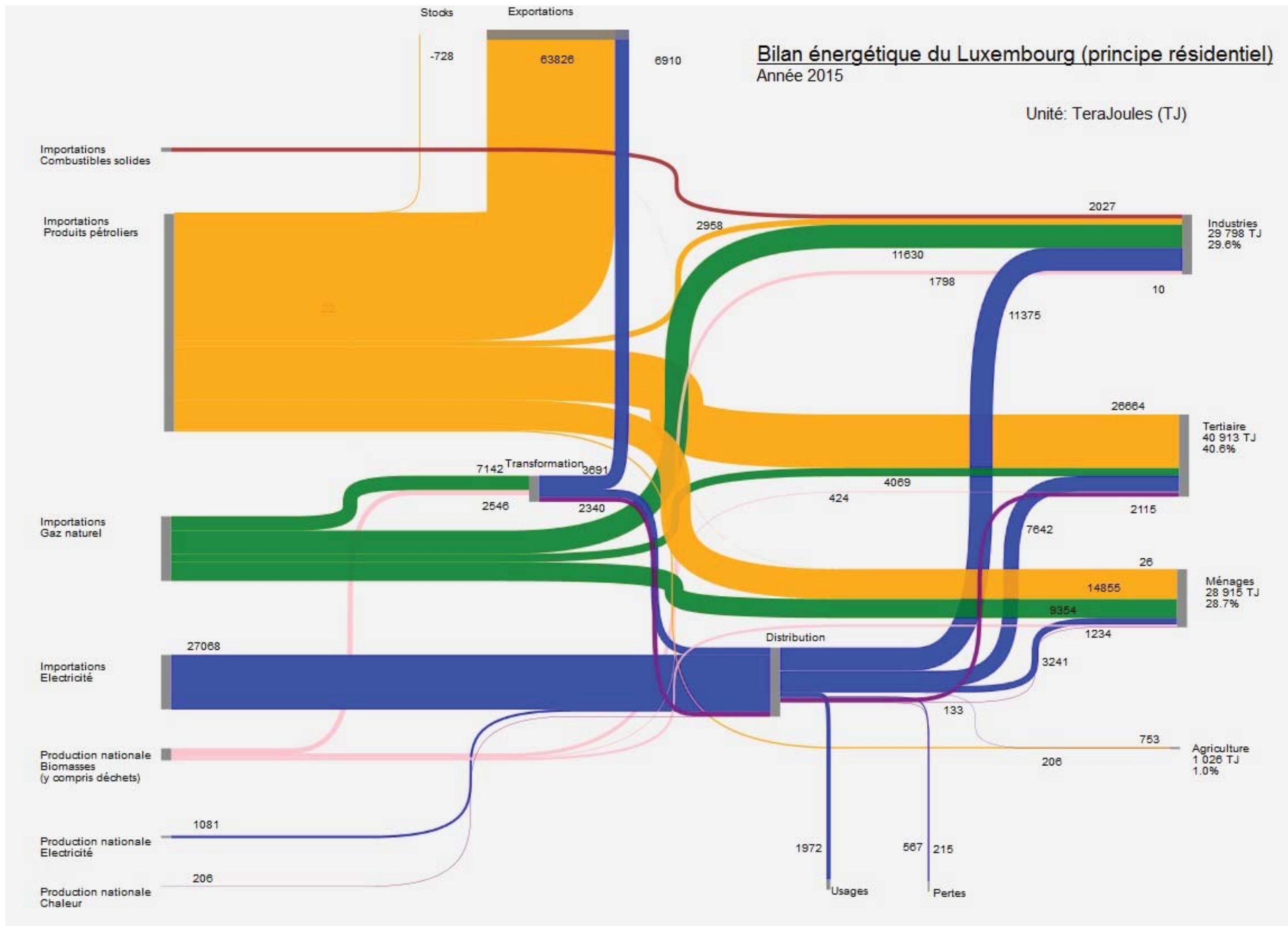


Fig. 6.1: Energy Balance in Luxembourg: The dependency on fossil fuels and on energy imports is clearly represented. (STATEC, 2015)

Luxembourg is highly dependent on energy imports. In 2018, its energy consumption totalled at 185TJ (STATEC, 2020), 95% of which was imported (IEA, 2020). Despite efforts to diversify its sources, oil still accounts for 65% and natural gas for 15% of the total primary energy supply, being both exclusively imported. Electricity imports account for 12%. As a result, the country has the highest energy consumption per capita among the IEA members. By 2030 the stated goal for Luxembourg is to increase its renewable energy share to 23-25%. By 2017 they reached 6.38%, and for 2020 they just missed their target by 2% (STATEC, 2020).

The transport sector takes the biggest share of the primary energy demand with 61%, followed by the industry (15%) and households (11%). Energy consumption of transport and households aspects are further analysed in the domains building stock, mobility and logistics.

A big share of the natural gas imports is destined for the industry where, together with coal, it is mainly used to power high-temperature processes, for example in the cement and metal industry. To become climate neutral, hydrogen can be an attractive sustainable solution for processes that are not feasible for electrification. Combined with the expected hydrogen demand for heavy transport, this requires the development of an efficient hydrogen import and distribution network.

Domestic energy production in Luxembourg, which is exclusively electricity, only accounted for 5% of their primary energy supply in 2018, despite the fact that this share increased by 58% since 2008. This is mostly due to the lack of storage other than the 90 days of average imports mandated by the EU, which further strengthens Luxembourg´s energy dependency (IEA, 2020).

While the population and GDP grew significantly (24% and 18%) between 2007 and 2017, the total final energy consumption declined 7%. Over the last years, a slight increasing trend can be observed. If the prognosed

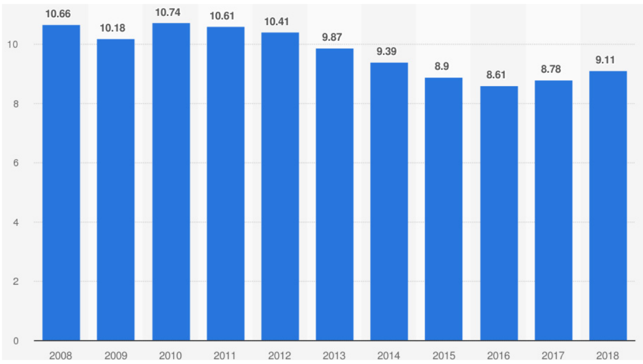


Fig. 6.2: Annual greenhouse gas emissions of the energy sector in Luxembourg from 2008 - 2018

Fig. 6.3: Electricity supply by sorts

demographic growth is reached and the energy efficiency in Luxembourg is not improved, the total primary energy supply will increase. (IEA, 2020)

Electricity

Electrical energy distribution occurs through two main grids. The first one, being operated by a partnership between the German TSO Amprion and the Luxembourger CREOS, serves most of the residential, commercial and industrial buildings. The second one, conceived for the heavy industries, such as the metal industry, is operated privately. As part of the EU energy security policy, an interconnector project (BeDeLux) was initiated to ensure a higher security of energy supply (IEA, 2020).

86% of electricity imports arrive primarily from Germany and secondly from France. The energy balance with Belgium varies, since Luxembourg also exports electricity there. Of the remaining 14% of electricity that is generated inland, 79% is produced from renewable sources (31% biomass, 26% wind, 12% solar, 10% hydro), and 21% is produced through the combustion of natural gas.

The actual electricity production differs from the installed capacity because of the intermittent nature of wind and solar energy production. In 2018, the biggest installed capacity was in photovoltaics (131MW), followed closely by wind power (123MW). However, the lack of storage capacity means that this potential is negated when production exceeds demand during favorable weather conditions. The hydroelectrical generators have been a constant supplier through time (IEA, 2020).
The renewable energy network is under constant development: Existing and planned wind turbines are mostly located in the north, while the solar photovoltaic panels are homogeneously distributed, along with the building stock. The charging docks for E-Mobility are concentrated in the South, as this is the most economically dynamic and commuter intensive zone of the country. Connecting supply and demand requires a robust and dynamic electrical infrastructure that can accommodate decentralized electricity production and is coupled with energy storage facilities to offset intermittent supply.

Changes are underway

Smart meters will replace 95% of the regular ones by 2020. The aim of this is to optimize the market process while obtaining useful consumer data. Simultaneously the customers can become active market participants with their generated electricity surplus. Private users are to be exempted from grid fees that apply to industrial providers.

Despite having a significantly lower ecological footprint compared to fossil fuels, the large-scale use and the ecological impact of photovoltaics in Luxembourg should be further investigated in order to determine the identified highest energy generation potential.

Luxembourg's tax on electricity for the industry is only half of the one in Belgium and one third of the one in Germany. It is assumed that

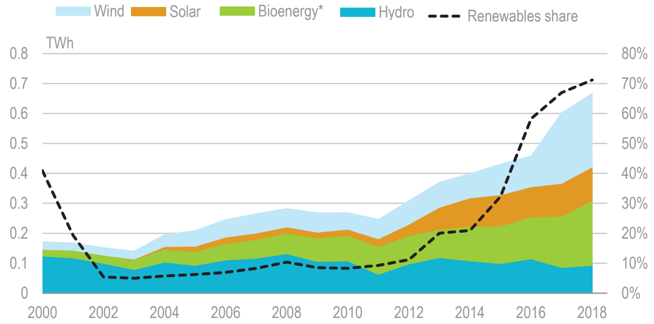


Fig. 6.4: Renewable energy in electricity generation, Luxembourg 2000-2018

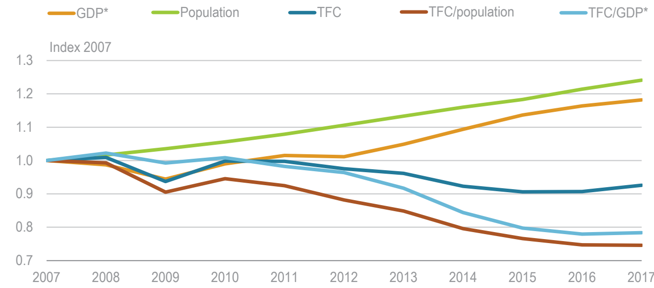


Fig. 6.5: Luxembourg's energy consumption, intensity, and drivers 2007-2017

this is part of a policy to attract manufacturing into the country. The tax for household's electricity is also lower than the neighboring countries (Luxembourg, 25%; Belgium, 31%; Germany, 54%). Likewise, Luxembourg has the lowest taxes for natural gas.

Retracing the paths of energy production and consumption is an opportunity to identify pathways for improvement. For example, when evaluating the energy consumption of building stock, the highest amount of energy is spent on heating. And while the natural gas availability is higher in the South, heating still has a 33% share of oil. As for renewable alternatives, restrictions are limiting the areas where heat pumps can be installed (Geoportal, 2020).

Further analyses and findings have been commented in the Buildings chapter. Likewise, the transport sector accounts its highest energy demand through its road transport (both individual and freight-related mobility), while rail plays a rather marginal role. For a country with an excellent quality railway system, concrete measures could be explored to improve the energy performance of the mobility and logistic sectors (STATEC, 2020).

In order to proceed with recommendations in later stages, we first summarized the key strategies and metrics that will be used to determine a path to decarbonization in the energy sector.

Strategy & Methodology

While the list below contains elements that imply a direct relation to other sectors, it is still relevant to adress them specifically in this section:

- **E.S.1.** Develop pathways to optimize energy infrastructure for renewable energy system, align with EU energy infrastructure programs
- **E.S.2.** Develop strategies for government programmes to increase energy efficiency (similar to SmartMeter initiative) and enable households to become energy producers
- **E.S.3.** Transition away from fossil fuels to reduce emissions and increase energy self-sufficiency. Simultaneously continue to expand inland and transnational distribution networks
- **E.S.4.** Analyse saving potentials in every sector and develop dedicated strategies, e.g., push for alternatives in freight transport, evaluate the building stock and adapt building standards to reduce the heating need
- **E.S.5.** Develop specific policies for high consuming energy typologies, e.g. data centers
- **E.S.6** Review tax policy on fossil fuels and energy carriers
- **E.S.7** Develop hydrogen import and distribution network to facilitate zero-emission industrial activity and heavy transport

Key Metrics

The following list is divided into three categories to show interdependencies to other fields:

<u>*Referring to primary energy consumption*</u>

- **E.KM.1** % kWh/per sector (share of energy consumed by sector from PEC each year)
- **E.KM.2** % kWh/fuel type (annual share of energy produced by source type from PEC)

<u>*Referring to Luxembourg's Policy*</u>

- **E.KM.3** Tax amount over fossil and renewable energy sources in %
- **E.KM.4** Ratio domestically produced energy / imported energy (indicator for energy security)
- **E.KM.5** Ratio energy production / energy consumption (indicator for energy self-sufficiency)

<u>*Referring to energy efficiency*</u>

- **E.KM.6** Lux-specific-CO_2 / kWh/renewable source (actual efficiency for different renewable technologies in Lux)
- **E.KM.7** CO_2 / GDP / Year (decoupling between economic growth and CO_2 increase) **E.KM.8** CO_2 / Inhabitants / year (decoupling between demographical growth and CO_2 increase

7. Agriculture, landscape, nature

Summary

The recovery of natural ecosystems requires long term collective efforts from the population, governmental, institutional and private sectors, in order to show measurable effects. In terms of reducing GHG emissions in agriculture, short-term feasible measurements include:

- ***Replacement of conventional cattle farming*** by organic alternatives, sustainable arable farming for human food or by forestry (carbon sequestration) (A.S.1)
- ***Reduce the use of chemical pesticides and fertilizers*** to initiate the transition from soil-polluting agriculture towards practices with a neutral soil balance, thereby improving groundwater quality (A.S.3)
- ***Increase wood production and reinforce the wood industry sector*** in order to create a local market for construction material and pellet heating for daily use (A.S.4)

In addition, if de-compartmentalization, afforestation and creating ecological corridors can be accelerated by restructuring the spatial configuration of the country, the resulting GHG absorption will contribute towards both the reduction of emissions, as well as help restore the country's ecosystem services and biodiversity.

The potential of these interventions will be shown in a scenario-map, in which the metamorphosis of the (urbanized) landscape in an ideal situation will be compared to the current situation, accompanied by the tentative difference in GHG emissions over time.

Analysis

In Luxembourg, 51% of the territory is active agricultural land, and (MAVD, 2020); 36.6% consists of forest, a situation which underwent little change during the last decade. The agricultural, forestry and fishery activities have altogether contributed to 6.55% of the total GHG emission of the country.

Unit: ha	2000	2010	2019
utilised agricultural area	127 643	131 106	131 592
arable land	60 927	61 951	61 959
meadows and pastures	65 277	67 526	67 884
other cultivated land	1 439	1 629	1 749
cereals	28 639	29 713	27 393
wheat and spelt	10 971	14 009	13 458
rye	672	896	1 137
barley	10 538	8 261	6 064
oats and coarse grains in a mixture	2 379	1 348	1 644
mais-grain	255	375	143
triticale	3 635	4 780	4 911
other cereals	189	44	36
pulses grown for seed	431	336	407
potatoes	829	615	601
industrial plants	3 344	4 867	3 931
rapeseed	3 245	4 715	2 883
fodder plants	25 523	25 371	28 545
maize	10 799	13 435	15 070
temporary meadows	14 178	11 461	11 745
fodder legumes	469	447	863
fodder beet	77	27	79
other crops	2	717	812
fallow land	1 527	139	269
meadows and pastures	65 277	67 526	67 884
horticulture	21	48	183
permanent crops	1 365	1 503	1 556
vineyards	1 249	1 266	1 286
orchards	53	133	174
nurseries	55	86	72
other permanent crops1	8	18	24

Agricultural land directly related to animal products

General division between livestock space and cropland

Fig. 7.1: Utilised agricultural area (2000-2019) (MAVD, 2020)

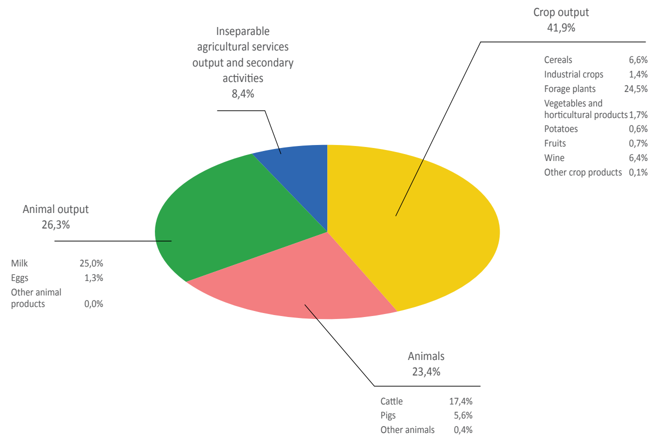


Fig. 7.2: Part of the different productions in the output of the agricultural industry at basic prices 2015 (MAVD, 2016)

<u>*Agriculture*</u>

Due to the focus on animal farming, the agriculture sector's GHG emissions per capita accounted for 1.42 t CO_2eq, much higher than the average EU number of 1.08 t CO_2eq (Ecologic Institute & Eclareon, 2014).

While 55% of the usable agricultural area is made up of meadows and permanent pastures, there are approximately 200.000 cows for milk and meat production. In 2019, the total number of exported cattle (including breeding and production cattle, meat-production cattle, and calves) was 10 times higher than that of imported cattle. With animal fodder being by far the most important cost factor for livestock farming, 70% of agricultural land is used for fodder production, thereby representing the most important output of Luxembourg's agriculture.

Since the introduction of chemical fertilizers and pesticides in the 1950s, the negative impact of agriculture on the natural environment has grown significantly. During the past decades, two-thirds of species (flora and fauna) in Luxembourg have been threatened by extinction. The economic success of fodder processing led to an increase in large, monoculture farms. A characteristic development is a steady decrease of the number of farms and farmers, and an increase in surface area per farm. The acceleration of intensive agriculture induced increased losses to habitat surfaces, resting and nesting areas, and food availability for wildlife. (CBD, 2020). Under this trend, the development of organic or bio-farming, which produces far less GHG emissions and promotes biodiversity, received little attention. The share of organic farming represented only 4.4% of the total agricultural land surface in 2018, while the European average is 7.5% (Eurostat).

In 2019, a new compensation allowance scheme was approved by the European Commission to face these challenges. The scheme, which will mainly benefit small and medium-sized, low-intensity farms, enables them to strengthen their competitiveness while preserving smaller farms and farm-households against intensification of agricultural land. The national action plan to promote organic farming called "PAN-Bio 2025" aligns with the new scheme, aiming for 20% of the Luxembourg agricultural sector to be organic by 2025 (MAVD, 2020). However, while Luxembourg quickly developed towards a service-economy, the labour force in farming decreased from 4292 annual work unit (AWU) in 2000

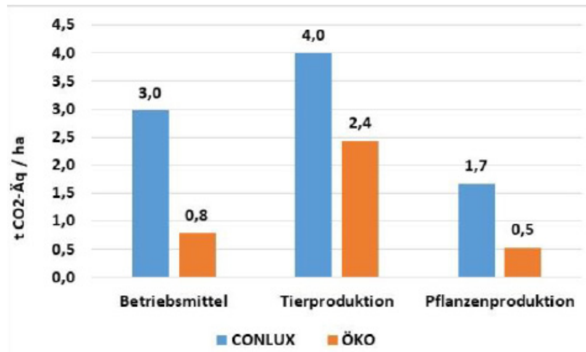


Fig. 7.3: GHG emision: conventional farming vs. ecological farming (MSDI, 2018)

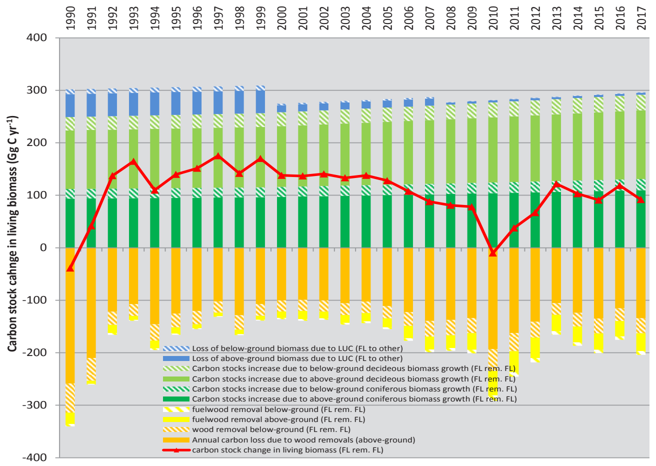


Fig. 7.4: Emissions and removals from forests as calculated in GHG (MECS, 2018)

to 3343 AWU in 2019 (MECS, 2020). Considering the fact that organic farming tends to be labour-intensive and requires devoted, well-trained farmers, the implementation of the plan remains challenging.

Forestry

Forest habitats and species have a more favorable conservation status than species and biotopes in open areas (CBD, 2020). From 2001 to 2019, no tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation (Global Forest Watch, 2020). From 2013 to 2019, 72% of tree cover loss in Luxembourg occurred only within plantations, and the total loss within natural forests was equivalent to only 316 kt of CO_2 emissions.

The wood industry in Luxembourg is dominated by one major producer of OSB and fibreboard panels. As a result, the carbon pool of

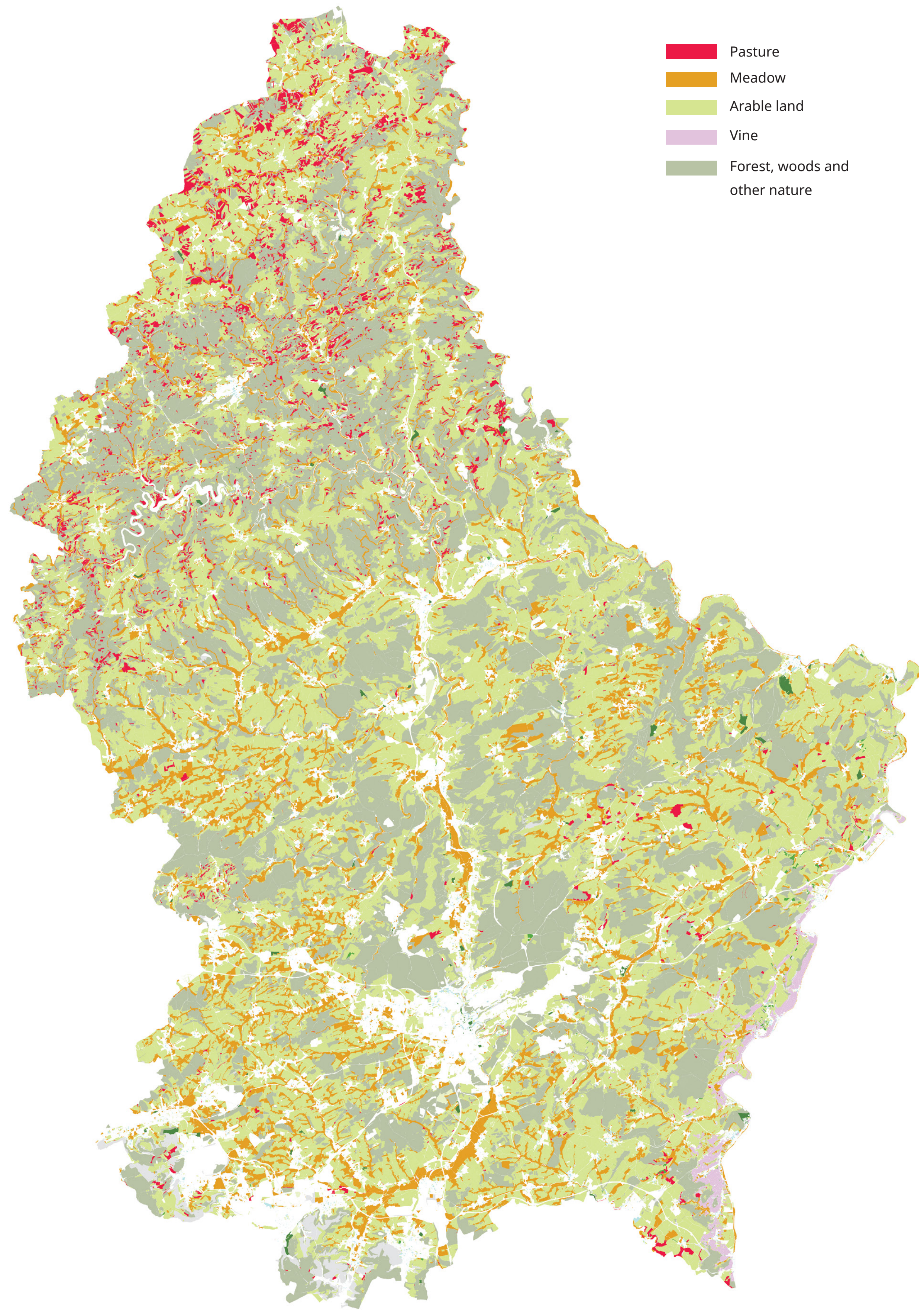


Fig. 7.5: Map of agricultural landuse (based on data from Geoportal)

wood-based panels is by far the most relevant carbon pool of HWP. It is estimated that only 10% of the wood that is needed for production originates from Luxembourg, and that most of the remaining wood is imported from Belgium. In fact, the production of wood-based panels is almost equal to the export of wood-based panels, because the domestic market for wood-based panels is too small compared to the production (MECS, 2020). This low demand for wood products in the construction industry is not only reflected in the low rate (6.9%) of wood in the construction industry (STATEC), but also in the low proportion of wood among the total construction/ demolition waste (Deloitte, 2017).

The use of wood for energy supply is also low in Luxembourg. Within the 500.000 m3 average annual volume of harvested wood, only 4% is used for energy (e.g. pellets). The fuel-wood production is only 0.03 m3 per capita, far below the EU average of 0.20 m3 per capita (Otepka & Grynenko, 2018). On the other hand, since the introduction of policies promoting renewable energy, more pellet heating units have been deployed in new residential buildings. Concerning existing buildings, owners will only consider investing new heating systems when amortisation becomes feasible. With a typical life expectancy of 20-30 years for heating systems, the use of wood will only increase gradually (MECS, 2020), if no stimulating measures are deployed.

Landscape & Nature

With high degrees of soil artificialization and habitat fragmentation, Luxembourg's biodiversity is under pressure. The conservation status of species is in a relatively unfavorable trend. As continuous degradation of wetlands, dry grasslands and extensively used orchards is proliferating, Luxembourg becomes one of the most fragmented countries in Europe (OECD, 2020a).

In the wake of this challenge, nature protection plans were made for serious implementation. Progress was made on the establishment and restoration of ecological corridors to

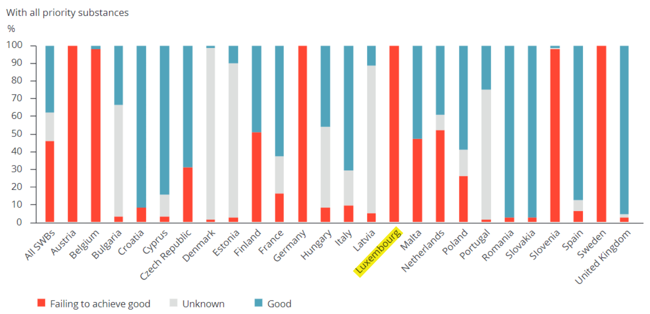


Fig. 7.6: Chemical status of all surface water bodies, comparision between EU countries (EEA, 2018)

increase the value, reach and performance of protected areas. In this process, Luxembourg's re-cultivation of urban area to semi-natural land was also the highest in EU, at a yearly rate of 82 m^2/km^2 (EEA, 2019b). In spite of that, the state of biodiversity conservation remains unfavourable, due to the growth of residential quarters, cross-border commuting and the development of transport infrastructure. The parallel pollution and forest monoculture also threat habitat- and species-protection. This condition is aggravated by climate change and the arrival of invasive species.

The degradation of nature is directly reflected by the state of water resources. According to a recent EEA report, hardly any surface waterbodies in the country achieved a good ecological status. The groundwater from the sandstone aquifer, which supplies more than half of the country's drinking water, is vulnerable to pollution. The Esch-sur-Sûre reservoir, which provides 43 % of the water supply to public utilities in Luxembourg, is also in a critical state of eutrophication (EEA, 2010).

Agricultural water consumption is relatively low in Luxemburg, compared to the steadily rising urban consumption and the gradual declining industrial consumption. However, livestock and dairy farming cause diffuse pollution (nitrates) and affect water quality (OECD, 2020b).

Strategy and methodology

Agriculture

- **A.S.1.** Discourage traditional cattle farming and encourage ecological farming by means of educational programmes, environmental tax, transition-subsidies and technical support.
- **A.S.2.** Diversify agricultural activities and plot rotation, in order to improve biodiversity of farmland.
- **A.S.3.** Reduce pollutants, like herbicides and pesticides, exchange by biological products and monitor the supply of nutrients to the soil, in order to improve soil and groundwater quality.

Forestry

- **A.S.4.** Trigger a renaissance of wood-production and -industry, promote wood as construction material and heating-fuel.
- **A.S.5.** Revitalize existing forest in order to bring ecosystems back to a non-degraded state.
- **A.S.6.** Increase carbon sequestration capacity by utilizing all understocked productive forest land.
- **A.S.7.** Reforest un(der)used built surface and farmland with restored ecosystems with highly GHG-absorbing vegetation.

Landscape & Nature

- **A.S.8.** Restore ecosystem services in urban areas, re-cultivate unused/abandoned plots.
- **A.S.9.** De-fragment and de-compartmentalize the landscape and create ecological corridors.

Key Metrics

- **A.KM.1.** Share of ecological farm land compared to the total farm land surface.
- **A.KM.2.** Coverage of pellet heating within the total building stock.
- **A.KM.3.** Increase of wood as construction material.
- **A.KM.4.** Status of sealed soil surface
- **A.KM.5.** Topsoil (0-30cm) organic carbon content
- **A.KM.6.** Wood carbon sequestration capacity
- **A.KM.7.** State of ecosystem restoration and connectivity
- **A.KM.8.** Habitat location and inventory of vulnerable local species
- **A.KM.9.**Visualize and quantify GHG emissions of ideal situation of replacement of cattle-farming by forest and human food production in a future landscape vision.

IV.

CONSOLIDATION

Consolidation

Identifying biggest potentials

Our preliminary analysis allowed us to identify the biggest contributors per domain to greenhouse gas emissions in Luxembourg. A sole characterization of these contributors might not lead to a concrete reduction of emissions due to a myriad of external factors, such as cost of implementation or the resistance of the population against change, among others.

As a subsequent step we suggest a further classification of the identified strategies within three dimensions: their speed of implementation, their emissions reduction potential, and the ability of Luxembourg's government to induce change. This step is essential to identify which interventions should be prioritized and will help us in the formulation of the roadmap for the next phases. The adjacent "coloured balls" figure IV.1 shows the intervention priorities in the above described setting.

Contexts, Domains, Time

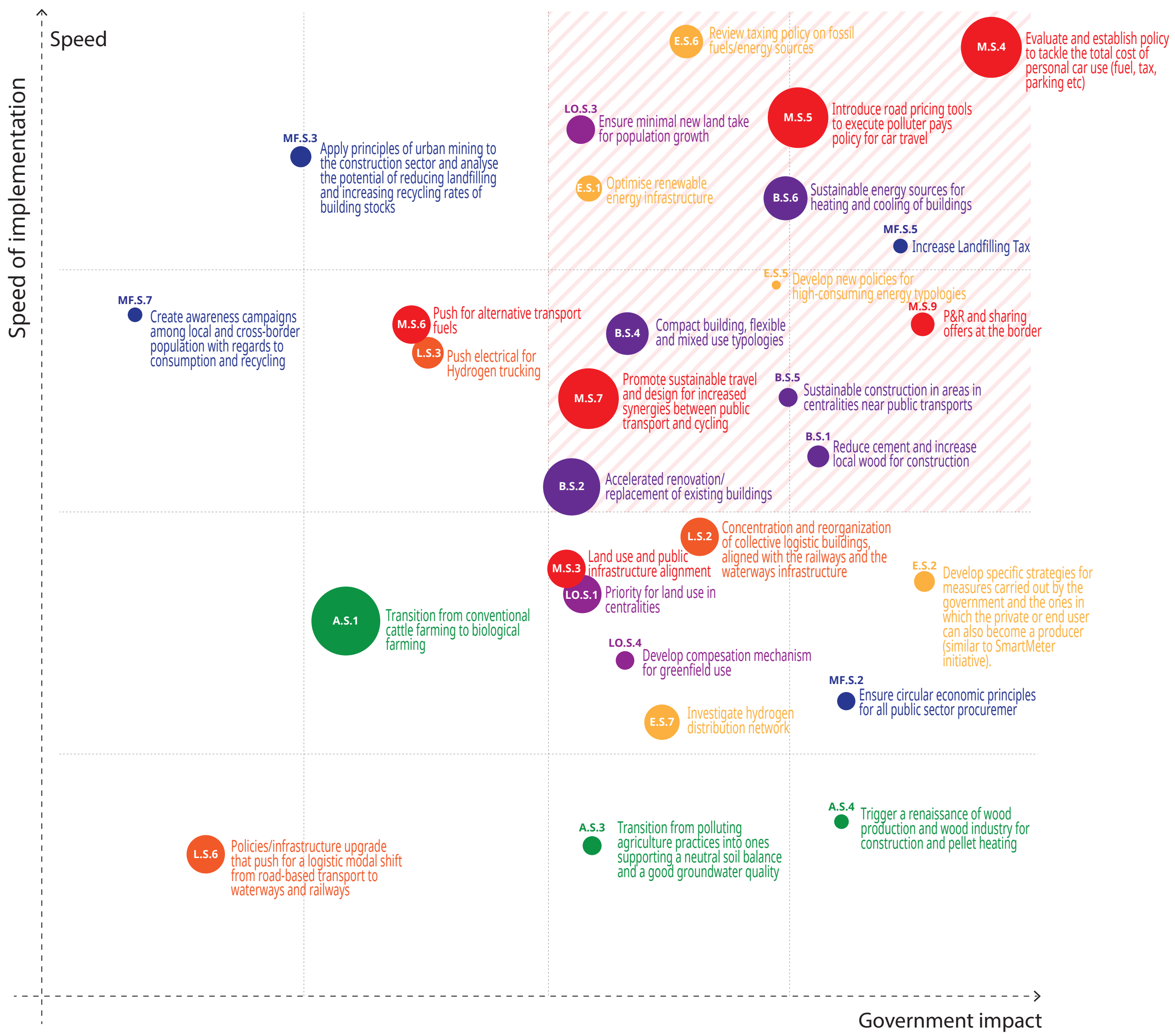
In addition, we will project the biggest contributors per Domain (***what***? Mobility, Logistics, Buildings, Land-use, Material flows, Energy, Agriculture) against the spatial and political backdrop of the described Contexts (***where***? Luxembourg 6 Geographies, Centralities, Transnational Exchanges, ***how***? EU-policy & Learning from Covid, Resilience) and link them to the timeline (***when***?). This is conceptually represented in figure IV.2.

For instance, ***where***, ***when*** and ***how*** can:

- multimodal transport turn the railway and tram into a decisive alternative?
- areas nearest to important public transport hubs be densified and transit-oriented locations created?
- pricing policies for road traffic and waste be introduced?
- renewable fuels be made mandatory?
- logistic parks be concentrated and aligned?
- transit share, last mile delivery and storage be aligned?
- renovation and retrofit be accelerated?
- compact mixed-use typologies be constructed around centralities?
- a binding central zoning planning-instrument be decided for Luxembourg with mandatory zones of built and non-built?
- borderline stakeholder workshops be organized that make people aware of the responsibilities associated to consumption and waste?
- renewable construction materials and construction waste be synchronized?
- local renewable power networks be constructed?
- a theoretical CO_2 reduction calculation of the replacement of cattle farming by a) forestry (sequestration) and b) sustainable crop production for food be debated?
- Trans-border issues be calibrated with the EU Green Deal policy?
- wood production and the wood industry be reinforced?

Three comparative Scenarios

Finally, we introduce three comparative scenarios to reduce GHG emissions as required in the brief during the timespan 2020-2030-2050. Significant in all three scenarios is the fact that with adequate policies and the sufficient acceptance to reduce the use of fossil fuels and road traffic, and to increase renewable techniques in the construction industry, the envisaged target can be largely met.



Status quo - Proposal (P) = tCO_2e Savings

$$P = e_{Mobility} + e_{Logistics} + e_{Buildings} + e_{Material} + e_{Agriculture}$$

E = total GHG-Emissions
e = emissions per sector

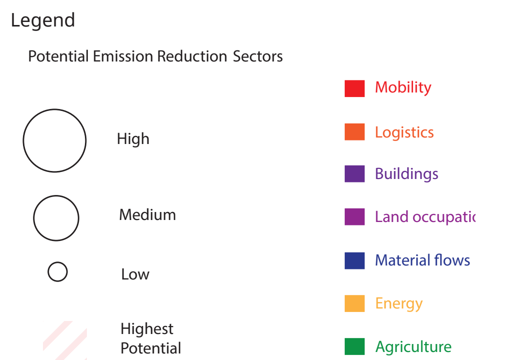


Fig. VI.1: Matrix of intevention's priorities

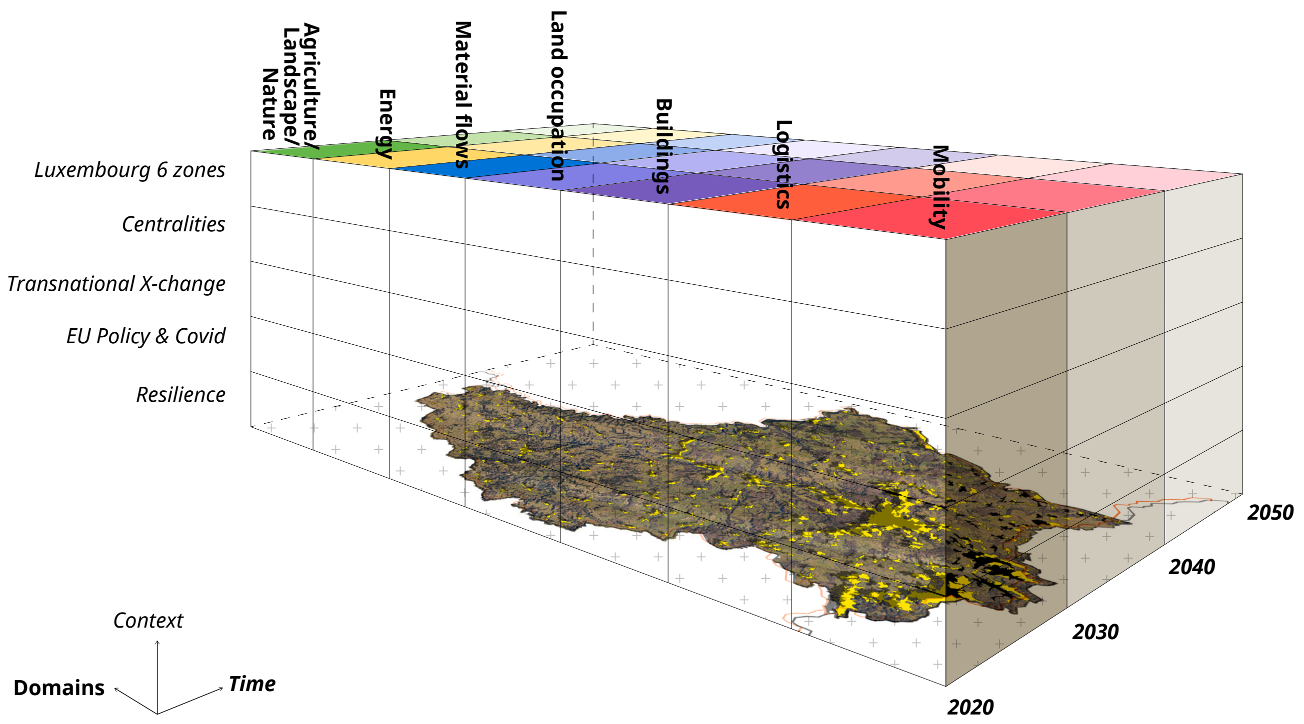


Fig. VI.2: Contexts, Domains, Time

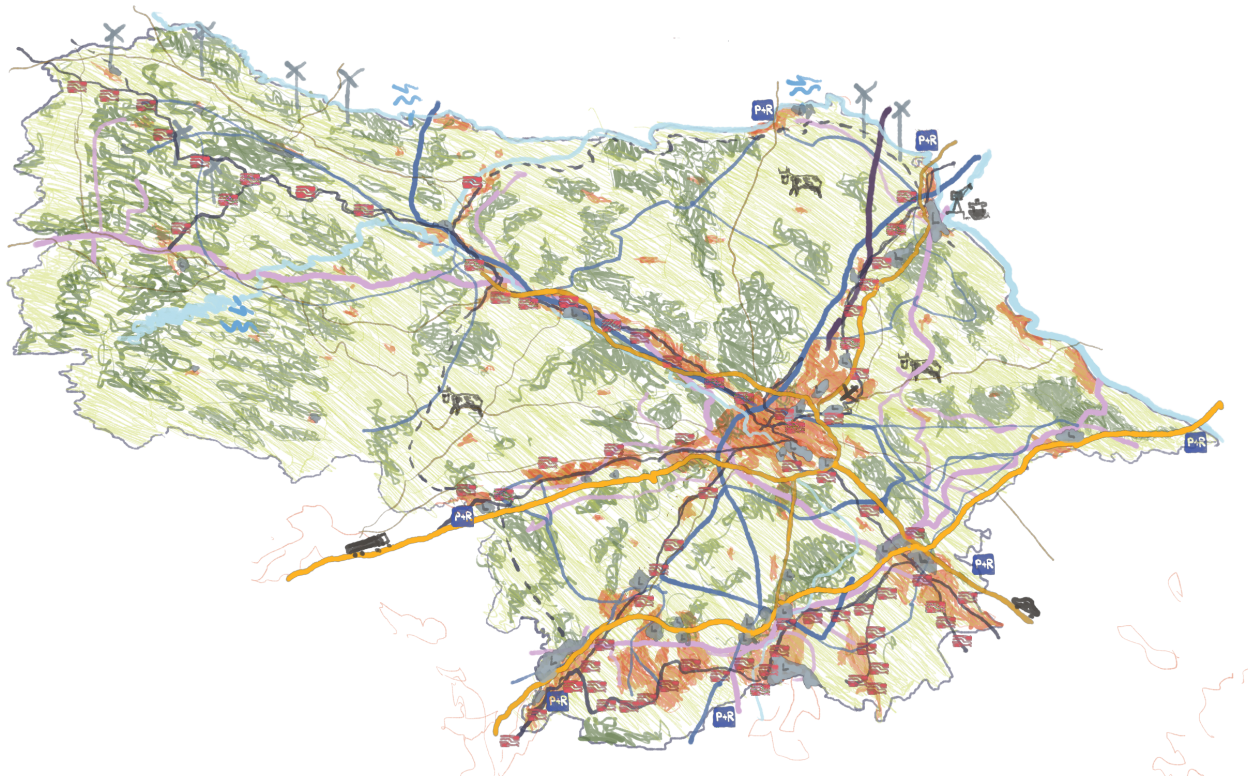


Fig. VI.3: Superimposition of domains

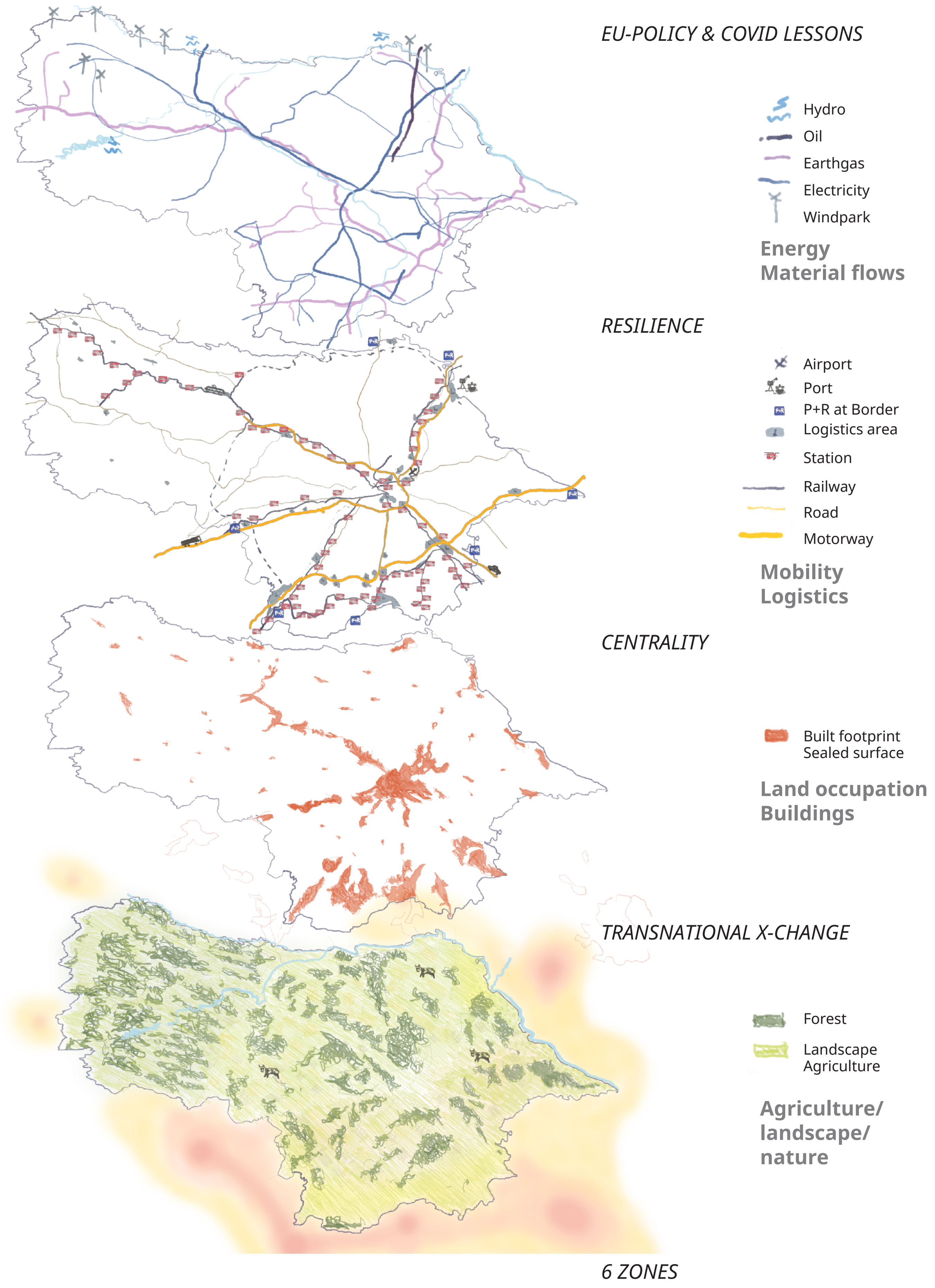


Fig. VI.4: Relation of contexts and domains

Three Comparative Scenarios

2020- 2030

Scenario 0
All sectors:
- Reduce to the goal of 45% of their 2005 record

Scenario 1
Mobility:
- Cut 67% of the existing fuel export in 2018
- Reduce 50% GHG emissions in car traffic in 2018

Logistics:
- Cut 67% of the fuel export in 2018
- Reduce 50% GHG emissions in light/heavy duty vehicles in 2018

Buildings:
- Reduce 50% GHG emission in resdiential buildings as in 2018
- Reduce 67% GHG emission in commercial and institutional buildings as in 2018

Other sectors stay the same as in 2018

Scenario 2
Mobility:
- Cut 80% of the fuel export in 2018
- Reduce 67% GHG emissions in car traffic in 2018

Logistics:
- Cut 80% of the fuel export in 2018
- Reduce 50% GHG emissions in light/heavy duty vehicles in 2018

Other sectors stay the same as in 2018

2030-2050

Scenario 0
All sectors:
- Reduce to the goal of 10% of their 2005 record

Scenario 1
Mobility & Logistics & Buildings:
- Slowly reduce to 10% of their 2005 record

Agriculture:
- Reduce 90% GHG emission as in 2018

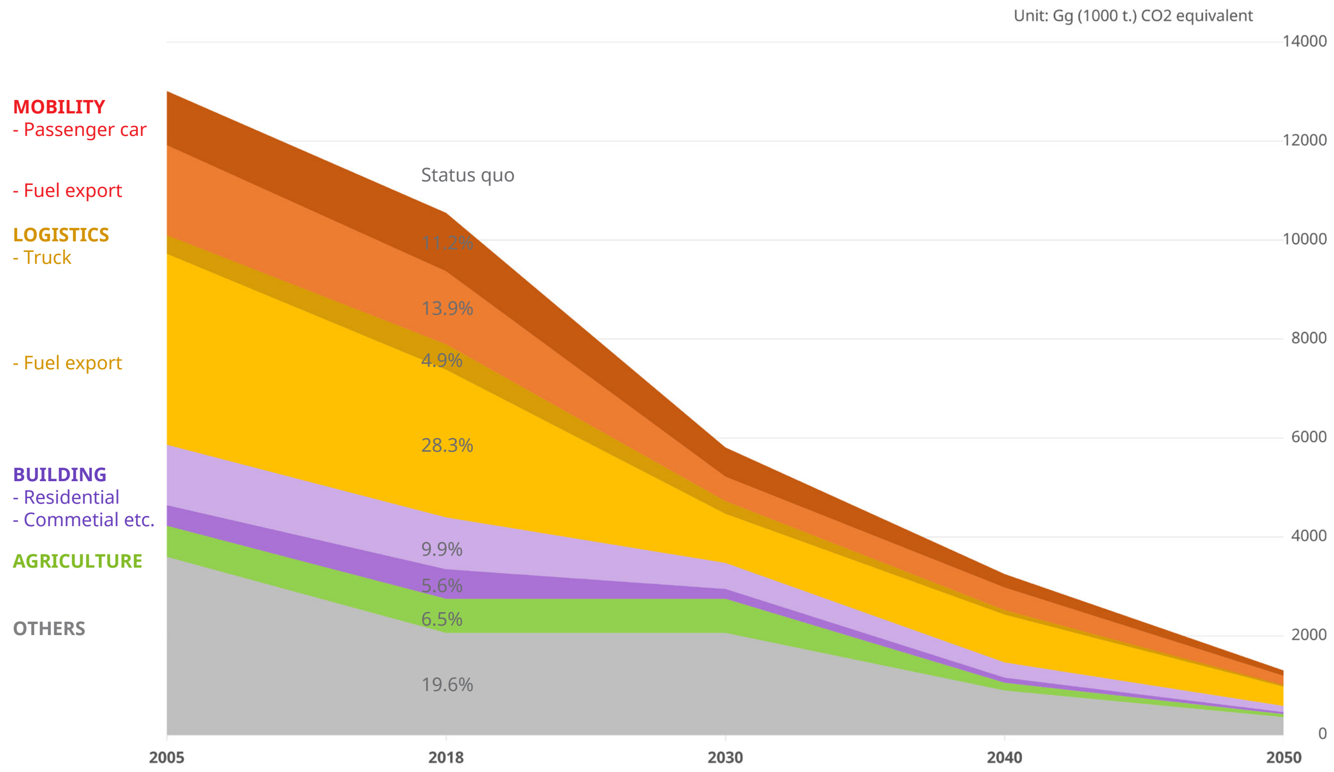
Others:
- Reduce 83% GHG in sectors such as manufacturing industry and construction, energy production, etc. as in 2018

Scenario 2
Buildings:
- Reduce 88% GHG emission from resdiential buildings as in 2018
- Reduce 93% GHG emission from ommercial and institutional buildings as in 2018

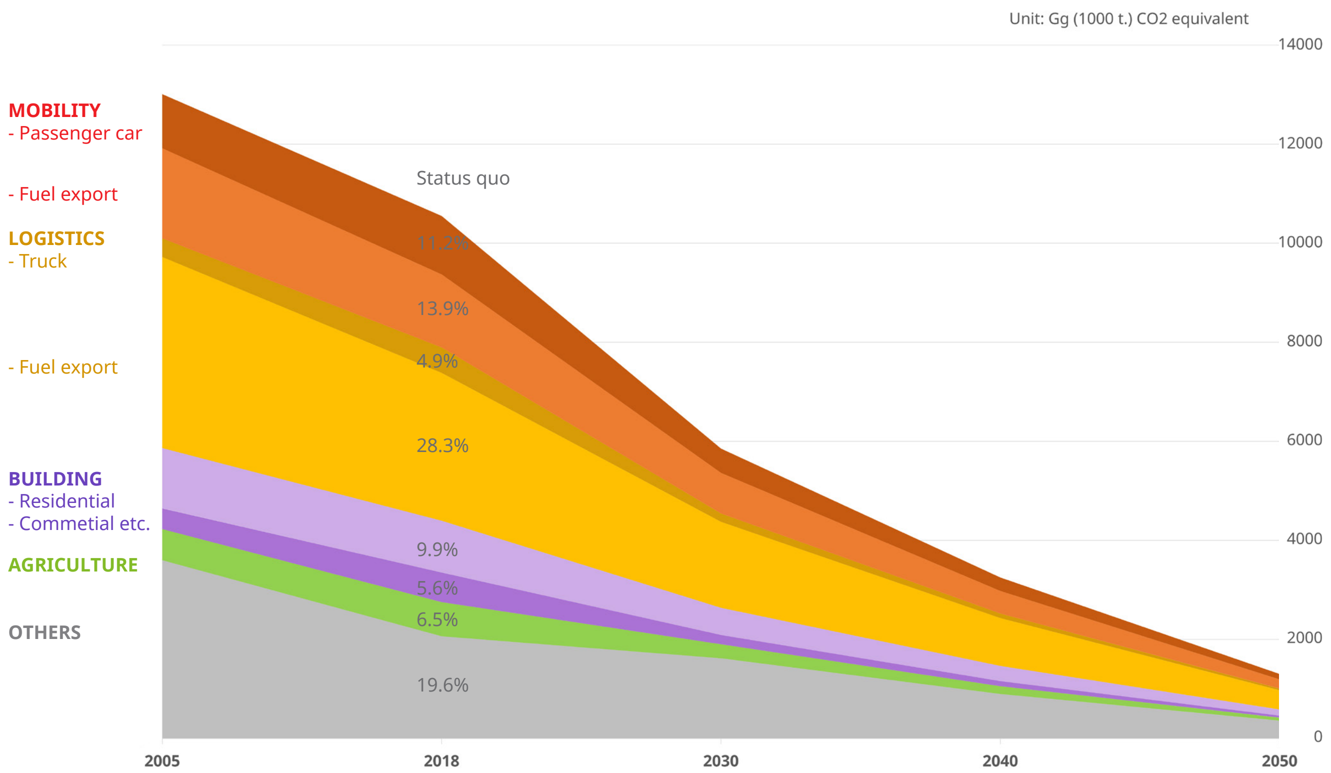
Agriculture:
- Reduce 90% GHG emission as in 2018

Others:
- Reduce 83% GHG in sectors such as manufacturing industry and construction, energy production, etc. as in 2018

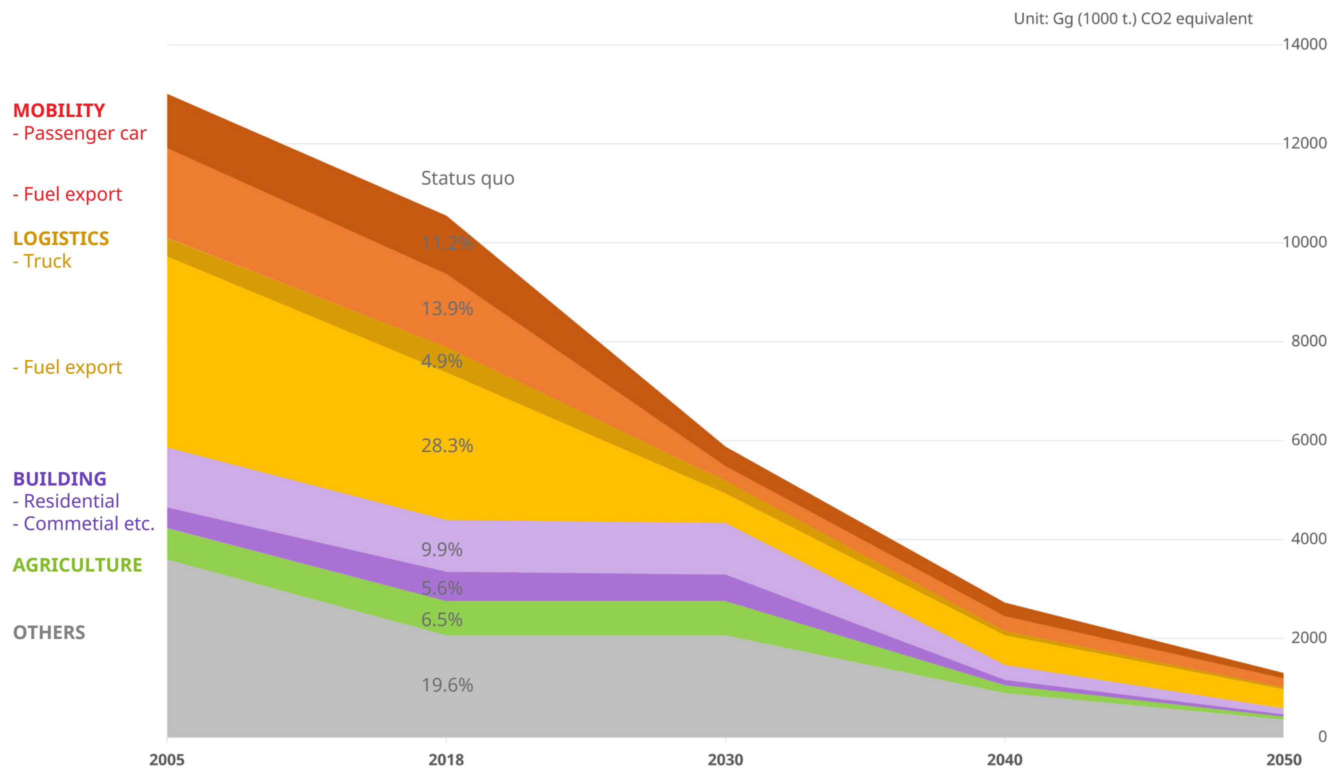
Scenario 1: Focusing on main GHG emitters -- mobility, logistics and building sectors



Scenario 0: Common practice -- all sectors reduce with the same proportion



Scenario 2: Focusing on main GHG emitters -- mobility and logistics only



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