MINISTRY FOR INNOVATION
AND TECHNOLOGY

National Clean Development Strategy 2020-2050

ITM

INNOVATION AT WORK

National Clean Development Strategy

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Abbreviations

AFOLU	agriculture, forestry and other land use
BAU	Business-As-Usual
CAPEX	captial expenditures
CBA	cost-benefit analysis
CCUS	carbon capture, utilization and storage
CNG	compressed natural gas
CNG	compressed natural gas
CO_2eq	CO_2 equivalent
COP	Conference of the Parties
COVID-19	SARS-CoV-2 pandemic/new type of coronavirus
CSP	concentrated solar panel
DSR	demand side response
EA	Early Action climate neutrality scenario
EBRD	European Bank for Reconstruction and Development
EEA	European Environment Agency
EGD	European Green Deal
EPR	extended producer responsibility
ESCO	Energy Services Companies
ESG	Environmental, Social, and Governance aspects
ETS	Emissions Trading System
EU	European Union
EUA	European Union Allowance
F-gases	fluorocarbons
FDI	Foreign Direct Investment
GDP	gross domestic product
GEM	Green Economy Model
GGGI	Global Green Growth Institute
GHG	greenhouse gas
GIS	geographic information system
GW	gigawatts
HIPA	Hungarian Investment Promotion Agency
HMKE	household-size small power plant
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IRENA	International Renewable Energy Agency
KSH	Central Statistical Office
LA	Action climate neutrality scenario
LCOE	levelized cost of energy
LED	lighting technology
LiDAR	Light Detection and Ranging
LNG	liquefied natural gas
LPG	Liquefied petroleum gas
LRF	linear reduction factor
LULUCF	land-use, land-use change and forestry
MEKH	Hungarian Energy and Public Utility Regulatory Authority
METÁR	system for the support of electricity produced from renewable energy sources
MIT	Ministry for Innovation and Technology
MNB	Central Bank of Hungary
MRV	Monitoring, Reporting and Verification
MSR	market stability reserve
NAS	National Adaptation Strategy
NAT	National Core Curriculum
NCCS-2	Second National Climate Change Strategy
NCDS	National Clean Development Strategy
NÉBIH	National Food Chain Safety Office
NECP	National Energy and Climate Plan

NES	National Energy Strategy
NFS	National Forest Strategy
OPEX	operating costs
OTKA	Hungarian Scientific Research Fund
P2G	power-to-gas
PEM	polymer electrolyte membrane
PJ	petajoules
PV	photovoltaics
RDF	refuse-drived fuel
RDI	research, development and innovation
S3	Smart Specialization Strategy
SCC	a szén társadalmi költségei (social cost of carbon)
SDG	Sustainable Development Goal
SMEs	small and medium-sized enterprises
SOFC	solid oxide fuel cell
SUP Directive	Single-Used Plastics Directive
SWOT analysis	an analysis of strengths, weaknesses, opportunities and threats
TKP	Thematic Excellence Program
TRL	Technology Readiness Leve
UHV	ultra-high voltage
UN	United Nations
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
V4	Visegrad Four Group

Foreword

In the Carpathian Basin in Hungary, we are experiencing the negative impacts of climate change—the most significant environmental, economic, and social problem of our time. The world we leave to our children and grandchildren solely depends on us. Therefore, instead of empty words, it is time to act. Hungary and the Hungarian government are committed to leading the way and choosing the path of action.

In January 2020, we set definite strategic targets in the field of climate change and environmental protection. We adopted the first *Climate Change Action Plan* that contains concrete measures for achieving the medium- and long-term goals of the *Second National Climate Change Strategy*. The *National Energy and Climate Plan* for the period up to 2030 and the new *National Energy Strategy* both contain clear objectives for the medium term. In the above documents, we pledge to make 90% of our electricity generation carbon-free by 2030. Besides reducing greenhouse gas emissions, we are also committed to strengthening energy security, reinforcing climate protection, and expanding economic development. Specific interventions of the *Climate and Nature Protection Action Plan*, adopted in 2020, also support environmental protection targets. The *Climate Protection Act*, also adopted last year, sets the goal to achieve climate neutrality by 2050. Finally, the *National Clean Development Strategy*, presented herewith outlines the pathways toward climate neutrality and confirms that the Hungarian government is taking concrete actions to combat climate change. With this background, Hungary is clearly choosing a clean future that follows the path of climate protection, energy sovereignty, and green economic development.

In the field of climate protection, Hungary pursues a reasonable and responsible policy. Climate neutrality must be achieved in a way that ensures the security of supply, a just transition, and economic development. The government insists that primarily the biggest polluters need to pay the cost of the transition and that increased utility costs for families must be avoided. Achieving the transition will not be an easy task. The following 30 years toward climate neutrality will be challenging since we are trying to reach a goal with some uncertainty along the way. What this transition means to our everyday lives is not yet fully clear, but we must stay on track with our common climate goal lighting the way.

Our country starts off from a favorable position on the journey toward climate neutrality. Hungary's performance is outstanding compared to other European and global emission levels. Since 2000, Hungary is one of the few countries that have managed to increase its GDP while reducing CO_2 emissions and energy consumption. The Hungarian economy has, in fact, been able to produce a unit of GDP with 24% less greenhouse gas emissions when compared to 2010 levels. The *National Clean Development Strategy* serves as a torch on the road toward a cleaner future, economic development, and improved social welfare.

Prof. Dr. László Palkovics
Minister for Innovation and Technology

Executive Summary

Our country has expressed efforts to support achieving climate neutrality by 2050 with the adoption of Act no. XLIV of 2020 on Climate Protection. The National Clean Development Strategy (NCDS or Strategy) outlines a 30-year vision of socioeconomic and technological development pathways. Hungary's long-term Strategy will help reach climate neutrality targets while focusing on the well-being of the Hungarian people and ensuring the protection of natural assets and economic development.

Hungary starts this endeavor from a strong position, being among the few countries since 1990 where the gross domestic product (GDP) has increased while CO_2 emissions decreased, by 33%. This confirms that climate protection, economic growth, and energy security are not necessarily conflicting objectives. By this, the long-term vision contributes to the United Nations (UN) Sustainable Development Goals (SDGs) by i) "Providing affordable, reliable, sustainable and modern energy for everyone," ii) "Creating sustainable consumption and production patterns," and iii) "Fighting climate change and its impacts with urgent response measures."

The NCDS was based on a wide stakeholder consultation process.

To outline the long-term trajectory, an integrated modeling approach was used to explore the specificities of the sectors as well as the system-wide and cross-sectoral dynamics of the decarbonization process. The development of projections was helped by applying two models:

1) The **Green Economy Model** (GEM) is an intersectoral model that uses system dynamics as its foundation. This methodology supports the estimation of the macroeconomic outcomes of decarbonization, including the economic evaluation of several social and environmental externalities in addition to changes in the labor market.
2) The **HU-TIMES model** was used iteratively with the GEM to simulate the energy sector and to outline the emission routes of the energy and industrial sectors. TIMES is a bottom-up, partial equilibrium optimization model used to analyze the different pathways of energy flow within the energy subsectors.

Three main scenarios for greenhouse gas (GHG) emissions up to 2050 have been developed and analyzed:

1) **Business-as-usual (BAU) scenario:** The emission trajectory of the BAU scenario follows current trends, assuming that all existing sectoral policy strategies and measures remain in effect, and that there will be no new interventions.

2) **Late action (LA) climate neutrality scenario:** This scenario aims to reduce emissions in the energy sector at a delayed and slower pace until 2045, and then with an increased effort until 2050. This allows the lower cost levels of low and zero emission technologies to be exploited. The scenario assumes that, in line with the targets set in the climate act, the final energy consumption could reach a maximum of 785 petajoules (PJ) in 2030, with the share of renewable energy increasing to at least 21%. After 2030, non-waste sectors will be on the lowest cost trajectory toward climate neutrality until 2050, which will result in accelerated emission reductions by 2050, due to the postponement of investments pending on a decrease in technology costs.

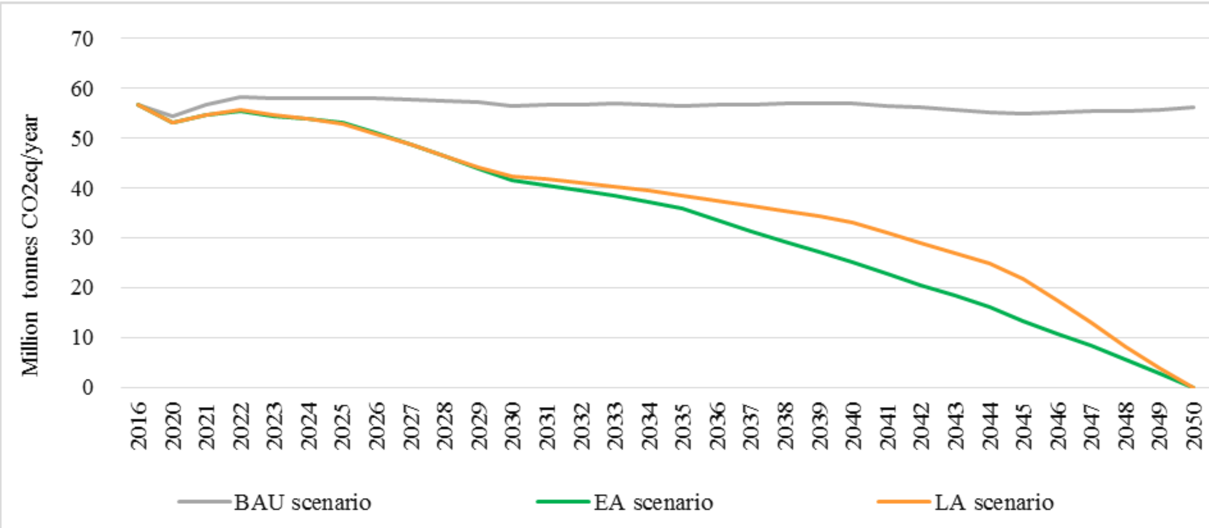
3) **Early action (EA) climate neutrality scenario:** the EA approach envisages achieving climate neutrality by 2050 while considering the short- and medium-term benefits of job

creation and a reduction of environmental externalities, the economic potential of the first mover, improved productivity, and higher GDP growth. The EA scenario assumes that Hungary's final energy consumption in 2030 will be a maximum of 734 PJ, and that renewable energy penetration will reach 27%. The emission reduction trajectories for industry; land-use, land-use change and forestry (LULUCF); waste management; and agriculture are the same as in the LA scenario. Between 2030 and 2050, emissions will follow a linear trajectory to reach net zero emissions.

In both the LA and EA scenarios, carbon capture, utilization, and storage (CCUS) technologies will become commercially viable in the energy and industrial sectors after 2030.

According to the modeling results, GHG emissions in the BAU scenario will decrease to only 56 million tons of CO_2 equivalent (CO_2eq)/year, from 2019 levels. **Therefore, a considerably stronger effort will be needed to achieve the 2050 climate neutrality target[1] than the policies and measures currently in effect.**

According to both climate neutrality scenarios, net zero emissions will be reached by mid-century. However, the clean energy transition will vary based on different assumptions, and the generation of socioeconomic benefits will differ in their development pathways (Figure 1).



Source: Eurostat data, projection based on own modeling results

Figure 1 – Expected change of total annual net GHG emissions for the whole economy under the three scenarios examined (CO_2eq/year)

During its December 10–11, 2020 session, the European Council decided to increase GHG reduction targets to 55% by 2030.[2] **Both climate neutrality scenarios of this Strategy fulfill this increased target.**

The emission reductions of the two scenarios will diverge during the mid-2020s, with a difference exceeding 800,000 tons of CO_2eq by 2030.

The EA scenario will require stronger mitigation efforts; however the increased investments

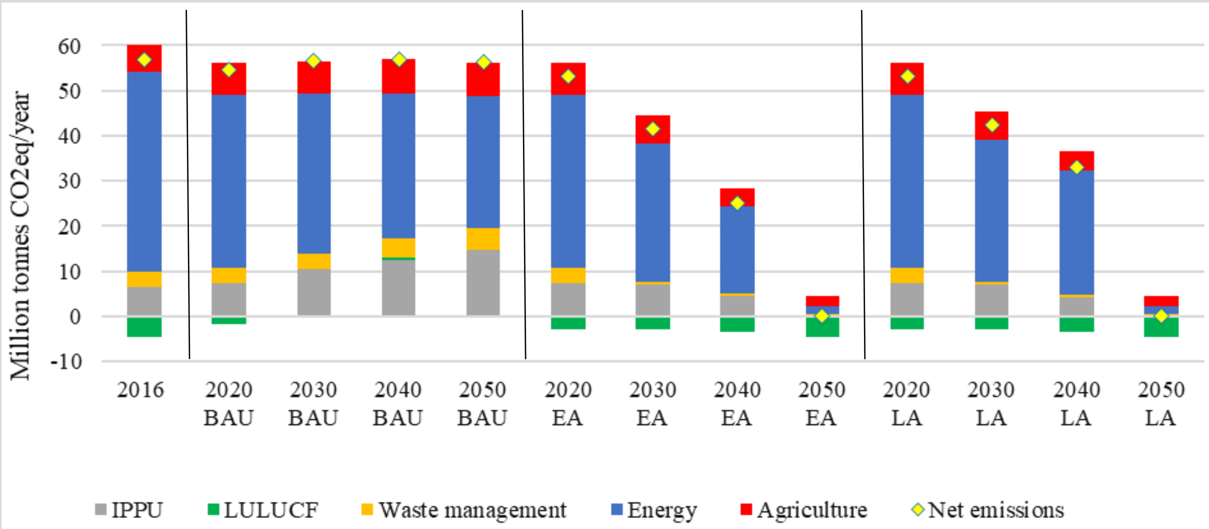
[1] Domestic emissions and absorption will be in balance by 2050

[2] European Council meeting (10 and 11 December 2020) – Conclusions Brussels, 11 December 2020 (OR. en) EUCO 22/20, CO EUR 17, CONCL 8

will boost country's economic growth. The end-user demand will increase including the demand for traveling and buying household appliances.

The **EA scenario follows a more gradual emission reduction pathway** since the investments serving the energy transition and decarbonization are carried out sooner. Furthermore, the EA scenario is characterized by an accelerated larger-scale "clean" electrification and decarbonization of the electricity system.

The sectoral distribution of GHG emission reductions under different scenarios is illustrated in Figure 2.



Source: Eurostat data, projection based on own modeling results

Figure 2 – Sectoral distribution of net GHG emissions under the three scenarios examined (CO_2eq/year)

The emissions of the energy sector, being the largest GHG-emitting sector, will fall under 1.7 million tons of CO_2eq/year according to the EA scenario. The LA scenario also forecasts emissions under 2 million tons of CO_2eq/year (the expected emissions is 1.9 million tons of CO_2eq/year) by mid-century. In contrast, according to the BAU scenario, the emissions of the energy sector can only be decreased to 29 million tons of CO_2eq/year with already adopted and applied interventions and policies.

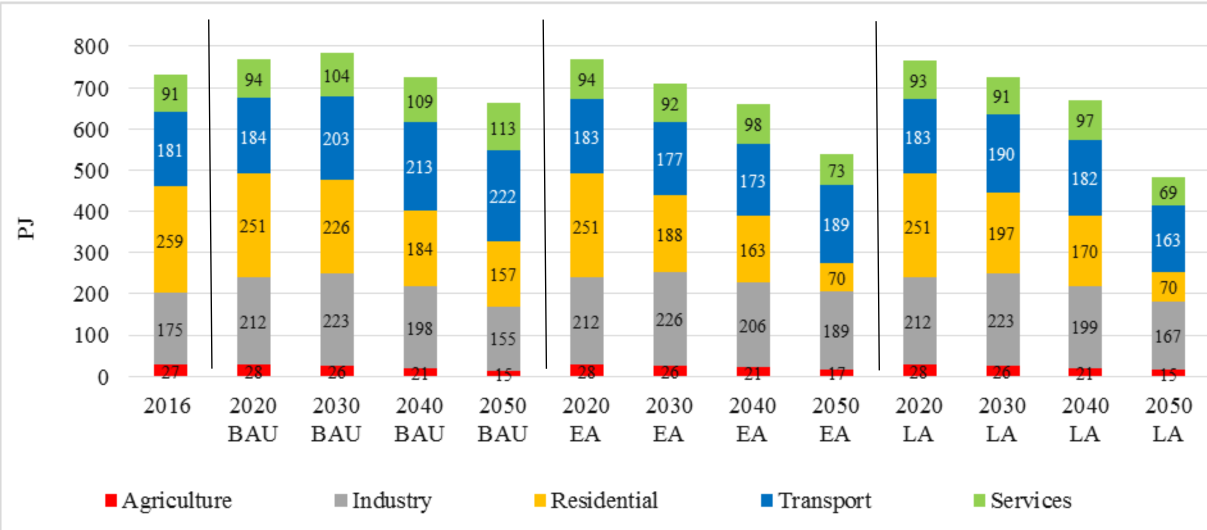
In the EA scenario, sectoral emissions after 2030 are consistently lower than in the LA scenario. Emissions from industrial processes are higher toward the end of the period, which can be explained by the larger-scale economic growth and the increase in industrial productivity provided by the EA scenario.

Natural sink capacities will be expanded to balance out the remaining emissions in 2050. It is forecasted in the EA and LA scenarios that 4.5 million tons of CO_2eq/year will be naturally absorbed, mainly due to the increasing forest coverage. Without additional interventions, however (according to the BAU scenario), forests will become net emitters (the GHG emissions of forests can reach a net 140,000–145,000 tons of CO_2eq/year).

The energy sector– including the energy supply and the energy consumption of the industry and transport sectors and others (such as tertiary or residential sectors) – **has the most significant role in reducing emissions.** This is because the energy sector accounts for 70% of total emissions and has the largest potential to reduce emissions (Figure 3). Consequently, **drastic changes are needed to decarbonize Hungary's energy supply system** (including energy generation capacities) **and to enable the end-user side to reduce energy consumption and utilize clean energy technologies.**

Under the BAU scenario, the final energy consumption between 2016 and 2050 can be reduced from 733 PJ to 662 PJ. However, this would not be enough to reach climate neutrality by 2050. **The final energy consumption is forecasted to be 538 PJ and 484 PJ by 2050 according to the EA and LA scenarios, respectively.** In the former case, the higher energy consumption is explained by the larger-scale economic growth indicated by the EA scenario.

Looking at a sectoral distribution (Figure 3), **the households (residential) sector has the largest energy saving potential.**



Source: Eurostat data, projection based on HU-TIMES modeling results

Figure 3 – Composition of final energy consumption by sector under the three scenarios examined, 2016–2050 (PJ)[3]

Even the BAU scenario shows reductions in household energy consumption due to the significantly lower energy use of new household appliances, newly built and energy-efficient buildings, and renovations and retrofits to existing buildings. As a result, the energy consumption of nearly 260 PJ in 2016 will drop under 160 PJ by 2050 in the BAU scenario. This value will be even considerably lower in the climate neutrality scenarios, where the household energy consumption will decrease to approximately 70 PJ by 2050.

The energy consumption of the industrial sector is different in the three examined scenarios. In the BAU scenario, the increase in energy consumption is dominant due to the higher GDP, which will be compensated by energy efficiency investments. A consistently decreasing trend can be observed from 2030 onward. **Overall, the two climate neutrality scenarios show a decreasing trend; however, some increase is forecasted until 2030. After 2030, energy consumption in the EA scenario will decrease at a lower rate than in the LA scenario.** This is explained by higher GDP growth and therefore higher industrial productivity in the EA scenario.

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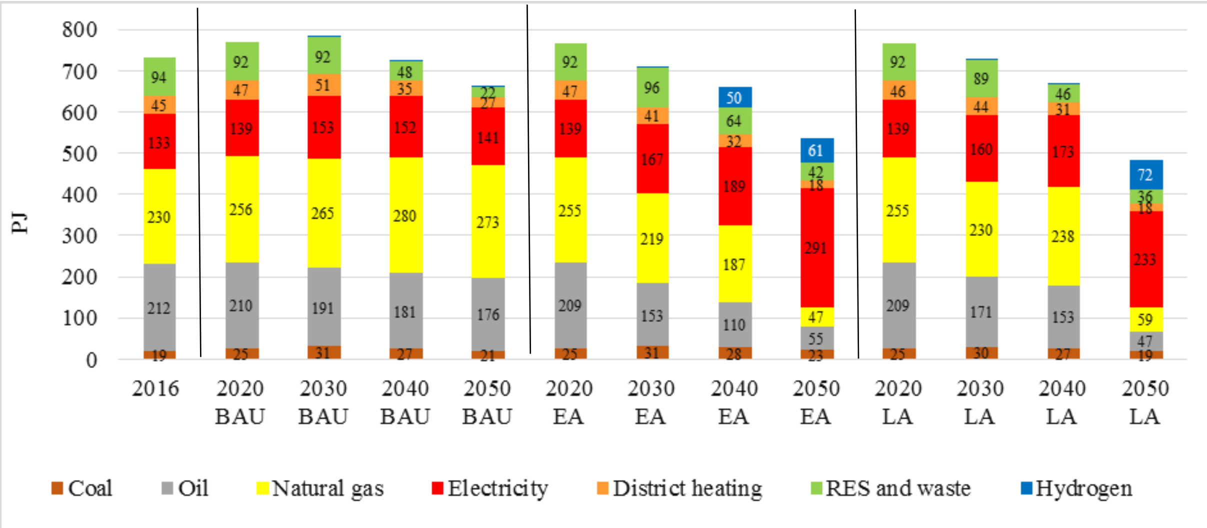
[3] Explanation: based on experts' judgment, the year 2016 was chosen as the baseline year for the HU-TIMES model

The service and transport sectors follow similar trajectories in the climate neutrality scenarios. In the BAU scenario, the energy consumption of both sectors slightly increases. The two climate neutrality scenarios show a 10–20% reduction compared to the current levels, due to energy efficiency investments and the use of more efficient fuels.

The fuel mix of the final energy consumption (Figure 4) **must change significantly to reach the 2050 climate neutrality target.** There is no significant shift of the fuel mix in the BAU scenario; however, the share of natural gas is increasing, which overshadows the renewable energy sources.



Source: Eurostat data, projection based on own modeling results

Figure 4 – Final energy consumption by fuel type under the three scenarios examined, 2016–2050 (PJ)

The most significant change caused by the two climate neutrality scenarios is due to large-scale electrification. For the EA scenario, the use of electricity accounts for over half of the total energy consumption, which is similar to the rate of the LA scenario.

As a result of electrification in the transport sector, **the consumption of oil-based fuels will decrease drastically**—to nearly a quarter of the current level—by 2050 in the climate neutrality scenarios. **The other significant change, which will start in the 2040s, is the decline in natural gas consumption** and the complete disappearance thereof in some sectors. Natural gas is partly replaced by hydrogen, mainly in the transport and industrial sectors. By 2040, **hydrogen will already play an important role in both climate neutrality scenarios.** By 2050, hydrogen will account for 11% and 15% of final energy consumption in the EA and LA scenarios, respectively.

To achieve net zero GHG emissions by 2050, based on currently available technological developments, **efforts are needed in the following areas:**

1) **Energy efficiency improvement** in all fields of the national economy and establishment of a circular economy;
2) **Electrification** in all areas of the economy, based on domestic nuclear and renewable energy sources;
3) **Application of CCUS technologies** in the energy sector and in high emitting industrial facilities;
4) **Use of hydrogen and upscaling of the related hydrogen technologies;**

5) **Sustainable utilization of bioenergy (within limits);**
6) **Sustainable, modern, and innovative agriculture;**
7) **Increase in natural sink capacities, mainly through the absorption of CO_2 by forests and maintaining forests as the most potential natural sinks as well as rethinking economic and financial incentives for forestry**; and
8) **Research, development, and innovation** as well as corresponding education and training programs.

Main directions for interventions:

- Support is needed for residential **energy saving**.
- Acceleration and expansion of **energy efficiency** investments are necessary, especially in the residential and commercial sectors.
- Significant investments will be needed to **electrify** the economy, especially in the transport, residential, and commercial sectors. One of the main conditions for the electrification of the economy is the modernization and climate-friendly transformation of the energy sector.
- Further investment will be necessary in the **development of CCUS technology**, as well as in the **increasing the utilization of renewable energy sources and energy storage systems**. Given carbon phase-out efforts, new investment in fossil fuel-based technologies and industries runs the risk of rapidly depreciating assets (i.e. stranded assets).
- Besides more efficient **industrial processes and product use** (IPPU), CCUS technologies and alternatives to replace fossil energy sources (as raw material feedstocks) are needed in the future. These alternatives can be carbon-free or low-carbon hydrogen and its derivatives as well as alternative biological raw materials. Furthermore, raising public awareness to shape consumption patterns and promoting the transition to a circular economy will have a significant positive impact on industrial emissions.
- Besides the electrification of the **transport** sector, expanding the application of **second-generation (or advanced) biofuels** and hydrogen, as well as the more efficient usage of fuels and the gradual decrease in using liquefied petroleum gas (LPG) on the market, will contribute to decarbonizing and modernizing the sector.
- In the **agricultural sector,** a reduction in fertilizer use; a more efficient use of organic fertilizers; and a wider application of precision farming, automatization, and digitalization will be needed. Moreover, investments targeting feeding, irrigation, and energy efficiency are key requirements. The **LULUCF** sector will require significant investments to enhance net CO_2 capture (sink capacities) after 2030. This will be especially needed for measures that improve forest adaptation, reduce logging in the medium term, and increase afforestation efforts in the long term. For sustainable forestry, the maintenance of stocks with the most optimal CO_2 equilibrium and business model (regarding area and age structure) needs to be emphasized. Furthermore, interventions should support maintaining and developing forests while protecting their natural levels despite climate change impacts.
- The **waste sector** will require significant investments to drastically reduce landfilling. Reducing landfills, diverging waste flows, and improving waste treatment methods account for around 90% of the emission reductions of the sector. Further investments will be needed to reduce the amount of industrial waste, to improve municipal waste treatment, and to

prevent waste in the first place. To reduce emissions in waste management, additional investments are necessary in other sectors (e.g., in the transport sector because of waste transport, or in the energy sector because of nonrecyclable waste combustion).

- **Research, development, and innovation** will be one of the main pillars of achieving our energy and climate goals. Through the research development and further improvement of new technologies and processes, as well as their market introduction, a degree of cost reduction can be achieved to greatly help the spread of clean technologies.
- The **education and (re)training** of professionals capable of developing and/or applying new technologies and processes is also crucial to reach climate neutrality.

Cost-benefit analysis

In order to achieve climate neutrality by 2050, significant investments will be required in the upcoming decades. However **the possible benefits of decarbonizing the national economy in the medium and long term will exceed these costs** (Table 1).

According to the EA scenario, the investment costs will be HUF 24.7 billion[4] higher compared to the BAU scenario. Conversely, the additional cost according to the LA scenario is HUF 13.7 billion. The difference between the two scenarios originates in the energy sector. The additional annual investment need accounts for 4.8% of the GDP in the EA scenario.

Based on the analysis, the **full decarbonization of the Hungarian economy will also generate significant avoided costs and added economic benefits.** Assessing the period up to 2050, the value of avoided costs and added benefits are observed to exceed the investment costs. Moreover, these avoided costs and additional benefits will continue to occur well after 2050; however, this is not discussed in this document. **Considering avoided costs and added benefits, the EA scenario is the most cost-effective scenario.**

Investing in the green transition brings macroeconomic benefits that lead to **significant boost in economic growth and create additional green jobs compared to the BAU scenario**.

Based on the EA scenario, the cumulated surplus GDP amounts to approximately HUF 19.8 billion—but only HUF 11.2 billion based on the LA scenario (Table 1, Figure 5). The **government revenues are forecasted to increase by HUF 11.1 billion cumulatively in the EA scenario** (while the LA scenario shows a growth of HUF 6.2 billion).

[4] 1 EUR = 350 HUF

	EA scenario	LA scenario
Investment costs – billion HUF		
Agriculture	745	745
Waste management	480	476
IPPU	129	131
Energy	22 391	11 352
LULUCF	964	96 473
Total investment costs	**24 709**	**13 668**
Avoided costs - billion HUF		
Material	2 393	556
Avoided energy cost	*2 142*	*305*
Avoided fertilizer cost	*251*	*251*
Nonmaterial	4 993	3 441
Avoided social cost of carbon	*2 604*	*2 269*
Transport-related negative externalities	*2 389*	*1172*
Total avoided costs	**7 387**	**3 997**
Added benefits – billion HUF		
Real GDP	**19 783**	**11 170**
Government revenue	**11 142**	**6 200**
Additional job creation – number of jobs		
Total net new jobs	**182 566**	**123 690**
Indirect employment creation	64 983	60 678
Direct employment creation	117 583	63 012

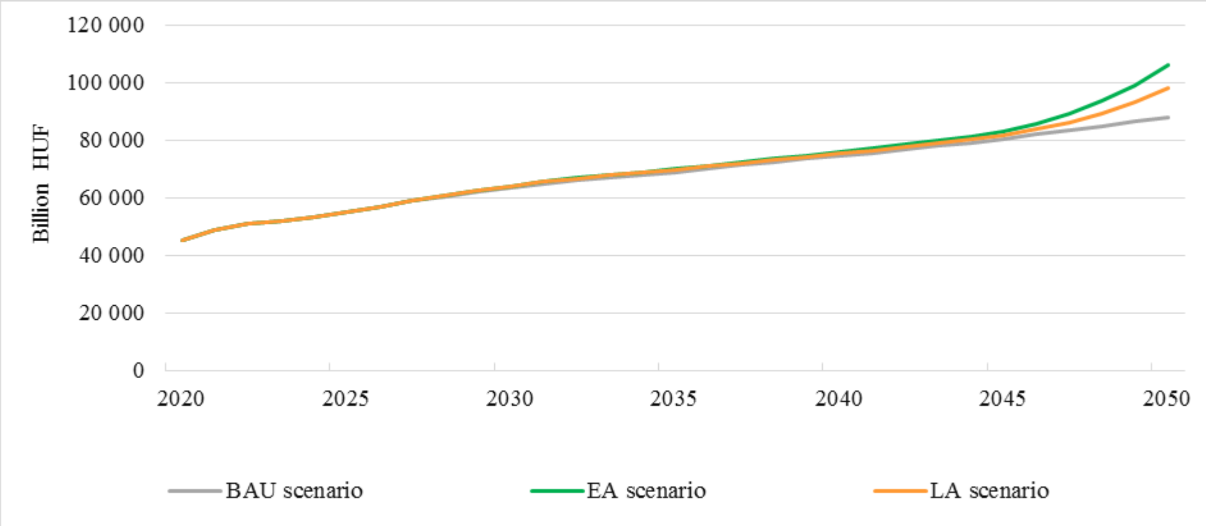
Source: own modeling result

Table 1 – Cost-benefit analysis for the periods 2020–2050 (additional costs and benefits compared to the BAU scenario)

According to the analysis, economic growth will be considerably higher after 2028. By 2034, the GDP and GDP growth trajectory will follow a similar path for the BAU and EA scenarios. **According to the EA scenario, it is estimated that the annual GDP growth will amount to an average 2.9%[5] between 2021 and 2050**. The expected growth rate in the same period is 2.5% in the BAU scenario.

Early investments identified by the EA scenario and the gradual and consistent reduction of emissions will result in a **20.7% higher GDP by 2050**, compared to the BAU scenario. The difference between the BAU and the LA scenario is only 11.3% (Figure 5).

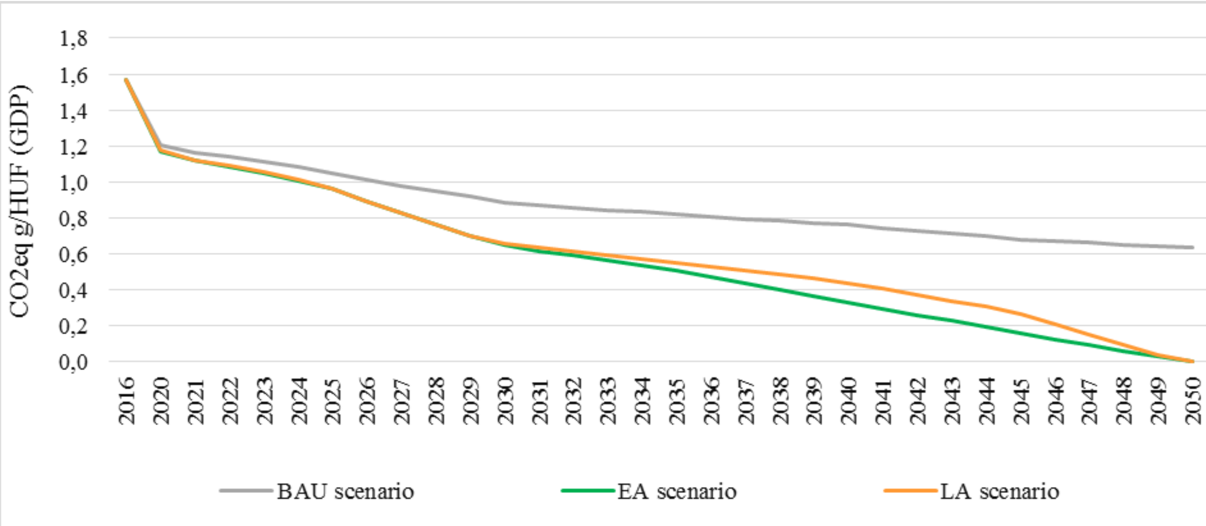
[5] Arithmetic average of annual real GDP growth rates projected for the period 2021-2050. A common method for calculating average annual growth rates is the use of the geometric average, which can be used to estimate an increase of 2.6% in the period under review. (See more information at: https://www.unescap.org/sites/default/files/Stats_Brief_Apr2015_Issue_07_Average-growth-rate.pdf)



Source: own modeling result

Figure 5 – Real GDP developments under the three scenarios examined

In addition, according to the EA scenario, **the carbon intensity of the Hungarian economy will gradually decrease** from 1.6 tons of CO_2eq/million HUF in 2016 to zero in 2050, while in the BAU scenario, a carbon intensity of 0.6 tons of CO_2eq/million HUF is expected by 2050 (Figure 6).



Source: Eurostat projection, own modeling result

Figure 6 – Carbon intensity of the Hungarian economy under the three scenario examined

According to the analysis, the decarbonization of the national economy creates new jobs in the analyzed sectors. The EA scenario indicates nearly **183,000 new jobs** created by 2050 compared to the BAU scenario, while the LA scenario shows only a third of this number. **Through appropriate education and (re)training programs, the Hungarian economy can benefit from a green transition**.

The analysis of the scenarios up to 2050 reveals that **the BAU scenario does not meet the increased 2030 GHG emissions reduction target nor the 2050 climate neutrality target set in Act no. XLIV of 2020 on Climate Protection**. **However, the cost-benefit analysis shows that the EA scenario brings considerably more economic and employment benefits than does the LA scenario**. At the same time, the EA scenario moderates the uncertainty of the technological transition, which is strongly present in the LA scenario. Furthermore, accelerating the energy transition and the early implementation of investments can incentivize a recovery from the economic crisis caused by the COVID-19 pandemic. **Therefore, in subchapter 4.2, which presents sector-specific results, the focus will be on a comparison between the BAU and EA scenarios**.

1. Long-term Vision and Guiding Principles of the National Climate Strategy

The objective of the NCDS is to **outline the socioeconomic and technological pathways toward achieving the 2050 climate neutrality target, which has been enshrined in law by Act no. XLIV of 2020 on Climate Protection.**[6] The Strategy prioritizes the prosperity, growth, and well-being of Hungarian families by integrating development and well-being goals into measures that prevent negative impacts or prepare for the unavoidable consequences of climate change.

Clean development is a model of development that nurtures sustainable economic growth and creates green jobs and economic development opportunities while minimizing environmental pollution and greenhouse gas emissions. The emissions reduction pathways presented in the NCDS integrate currently available and future technological solutions and show that it is possible to achieve the 2050 climate neutrality target in a socially just and cost-efficient way.

While achieving climate neutrality requires significant effort in all sectors of the national economy, action by the polluting industries and the private sector is essential. The government of Hungary is determined to ensure that the biggest polluters pay for the majority of the costs associated with the transition and that Hungarian families do not bear the costs of the transition. Although climate neutrality requires significant investments, it also presents major welfare opportunities –for the next 30 years and after – by laying the foundation for sustainable economic growth.

Although the green transition offers unique opportunities, it also holds challenges and temporary trade-offs. For this reason, the Strategy emphasizes a just transition through which everyone shares its benefits despite facing temporary difficulties. By undertaking this approach, the NCDS promotes public acceptance of ambitious climate action by demonstrating that the benefits can compensate for the negative impacts associated with the climate mitigation measures.

The long-term vision of the NCDS should be underpinned by promoting research, development, and innovation as well as continuous improvement at all levels through education and training and enhancing green finance opportunities.

Hungary starts this endeavor from a strong position, being among the few countries to prove that economic growth and climate protection are not necessarily conflicting objectives. Since the 1990s, the GDP of Hungary has increased while CO_2 emissions and energy consumption decreased by 33% and 15%, respectively. In 2020, Hungary became the first country in the Central Eastern European region and the seventh in the world to adopt a climate neutrality target in the form of a law with the adoption of Act no. XLIV of 2020 on Climate Protection by the National Assembly. Hungary is now determined to implement its climate neutrality goal by taking concrete steps.

The NCDS refines the path outlined in the medium term in the Second National Climate Change Strategy (NCCS-2) adopted in 2018 as well as in the National Energy and Climate Plan (NECP) and the National Energy Strategy (NES), both adopted in 2020.

The NCDS is the result of extensive stakeholder consultations, as well as robust modeling and analysis of future low-carbon scenarios, which allowed the exploration of the impacts of policy and technological interventions regarding socioeconomic objectives. The NCDS

[6] Government of Hungary (2020). Act no. XLIV on Climate Protection in 2020. Available: https://net.jogtar.hu/jogszabaly?docid=A2000044.TV&searchUrl=/gyorskereso

provides a forward-looking vision of the transformation that is needed to meet the 2050 goal and reduce the risk of stranded assets while avoiding carbon-intensive lock-ins in infrastructure.

Hungary is pursuing the following long-term goals by 2050 in all key sectors:

- **Energy**: **a decarbonized clean, smart, and affordable energy sector** for the Hungarian people and businesses that is decentralized, efficient, secure, interconnected, sovereign, and builds upon renewable and nuclear energy. The energy sector will store and utilize any remaining carbon emissions as well as weather-dependently produced energy. The decarbonization of the energy system will provide green jobs and help people financially by making them "prosumers."
- **Transport**: **a more sustainable, greener, safer, and better-connected transport system** supported by high-tech infrastructure and built on the right balance between public and private transport while recognizing the right to choose one's travel method. It will incentivize low-carbon transport modes and provide cleaner air, less noise pollution, and safer living spaces.
- **Industry and businesses**: **a climate-friendly, innovative, and knowledge-based industry and circular economy where Hungarian high-tech and green small and medium-sized enterprises (SMEs) have a leading role**. Undertaking the transition based on this Strategy will make Hungarian SMEs and industry the biggest winners of the green transition, further contributing to clean economic development and the well-being of Hungarian people.
- **Agriculture**: **a healthy, productive, climate-resilient, and high-quality agriculture sector** that ensures food security for all Hungarians and an efficient market environment that can produce items for export. In the beginning of the 2030s, a digital era will gain ground in zero-pollution, circular, and waste-free agriculture based on the toolset of Agriculture 5.0 (robotics, drone-based remote sensing, and automatization; industrial production of protein, carbohydrates, and bioactive material; molecular farming; functional soil and manure; functional food and feed production; and bioherbicides and biopesticides).
- **LULUCF**: **healthy and climate-resilient forests and grasslands**. Similar to agriculture, geographic information systems, digitalization, and automatization tools of farming will gain ground. The afforestation programs will utilize more resilient variants of local native tree species. Natural sink capacities that are essential to achieve climate neutrality by 2050 will be maintained and expanded.
- **Waste**: **a clean country with minimum or nearly zero waste**. Being the smallest GHG-emitting sector and in line with the European Union (EU) circular economy targets, waste should be treated as raw material and must be reduced, reused, and recycled to the fullest extent.
- **Financing**: **a financial sector that is in harmony with sustainability and aligned with the climate neutrality goals as well as a climate-friendly budgetary policy that supports green economic growth.** The flow of public and private funds is consistent with the financial needs of national green and climate protection investments.

To maximize benefits during the transition and translate the vision and values of Hungarians, the following guiding principles lead policy-making in the respective areas:

- **Contextuality:** National policies and measures shall be aligned with Hungary's commitments under international and EU laws.
- **Unity:** The proposed measures shall be valid in the context of the whole Carpathian Basin, since it forms an integrated ecosystem.
- **Comprehensiveness**: Actions shall equally fulfill the challenges ahead of the national environment, society, and economy. Interventions that prevent the negative impacts of climate change are equally important as measures that foster behavior change.
- **Utilization of zero-carbon energy sources:** A climate-neutral Hungarian economy shall be built on the utilization of renewable energy sources as well as on nuclear capacities. The 2050 climate neutrality target cannot be reached without the utilization of nuclear energy, thus both sources need to be considered.
- **The "polluter pays" principle, environmental responsibility, and social fairness:** The costs of the green transition should be primarily borne by the highest-emitting companies. Therefore, proposed measures should be based on proportional and reasonable logic.
- **Cost-efficiency:** Commitments shall be met at the lowest possible net cost to Hungarian taxpayers, consumers, and businesses.
- **Maximizing benefits:** The social and economic benefits for Hungary from the green transition shall be maximized.
- **Sovereignty and security of supply:** Only those actions and policy options that respect Hungary's sovereign decision-making power, energy independence, and security of supply shall be considered.
- **Application of research, development, and innovation and the development of the related education training background:** Promoting technologies and low-carbon solutions that innovatively facilitate the green transition is of key importance to meet the climate targets. Therefore, it is essential to improve skills and knowledge related to the development, production, installation, and application of new solutions.
- **Sustainability:** Only those technologies and low-carbon solutions that are ecologically and socially sustainable will be promoted.
- **Sustainable land use:** Maintaining biologically active areas will be emphasized while utilizing land use measures under the NCDS.

2. Policy and Legal Context

In **2015**, under the historic **Paris Agreement**, all nations agreed to actively participate in combating climate change. Article 4 of the Paris Agreement clearly states that the long-term goal of the collective efforts is “to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.” This balance (i.e., climate neutrality) - based on the Special Report[7] by the Intergovernmental Panel on Climate Change (IPCC) - is to be achieved globally by 2050, to avoid the worst effects of climate change.

According to the United Nations Environment Programme’s (UNEP) *Emissions Gap Report 2019*[8], global GHG emissions continue to rise. Over the last 10 years, GHG emissions have risen at a rate of 1.5% per year, and in 2018, GHGs achieved record highs. Based on the report, there is no sign of GHG emissions peaking in the next few years, and every year of postponed peaking means that deeper and faster cuts will be required. According to the *Emissions Gap Report 2019*, by 2030, global emissions would need to be 25% and 55% lower than in 2018 to put the world on the least-cost pathway to limit global warming to below 2˚C and 1.5°C, respectively. This could only be tackled effectively if all countries do their fair share based on their common but differentiated responsibilities and respective capabilities considering national circumstances as stated by the United Nations Framework Convention on Climate Change (UNFCCC).

Hungary is leading by example, although it is only responsible for approximately 0.15% of global GHG emissions. Hungary has adopted ambitious commitments under the first and second commitment periods of the Kyoto Protocol, which have been significantly overachieved. According to the *2020 National Inventory Report*[9], compared to the Kyoto base year (average of 1985–87) and to the internationally used base year of 1990, Hungarian GHG emissions in 2018 were lower by 43% and 33%, respectively. Hungary was the first country within the EU whose parliament unanimously voted to ratify the Paris Agreement. In December 2019, Hungary voted in favor of the EU 2050 climate neutrality target, and the Hungarian parliament adopted **Act no. XLIV of 2020 on Climate Protection,** which contains the legally binding obligation for the country to achieve climate neutrality by 2050. This complies with the international benchmark and the necessary targets proposed by the scientific community.

It should be noted that climate change is not the only environmental and social challenge that the world and Hungary are facing and which requires concerted global action. To address the most important problems under one comprehensive framework, the United Nations General Assembly adopted the *2030 Agenda for Sustainable Development*[10] in 2015.

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[7] IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.
Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

[8] UN Environment Programme (2019). Emissions Gap Report 2019. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y

[9] National Meteorological Servies (2020). National Emission Inventory Report 1985-2018. Available at: https://unfccc.int/documents/226419

[10] UN General Assembly (2015). Transforming our world: the 2030 Agenda for Sustainable Development. 25 September 2015. Available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf

As a Member State of the EU since 2004, EU policies and legal environment are greatly relevant in the Hungarian context. The EU has started an exemplary transition process with the adoption of the common 2050 climate neutrality goal and the initiation of the **European Green Deal** (EGD). The current EU-level environmental and climate protection regulations in force and the ongoing elaboration and implementation of the EGD fundamentally influence the opportunities and policy decisions of Hungary. Consequently, during the elaboration and implementation of the NCDS, this legal context played an influential role and is referred to in this text; however, a detailed description of it is outside the scope of this Strategy. To present the policy and legal context of the NCDS, Annex 2 lists the most relevant international EU-level and national documents. If the necessary innovations, energy efficiency measures, human resources, and industrial and renewable capacities are realized in Hungary and the EU before other regions, it will ensure a first mover advantage. The same applies to Hungary in comparison with other EU Member States.

The Hungarian government strongly believes that enhanced regional cooperation will be key to achieve and maintain climate neutrality. As a member of the **Visegrad Four Group (V4)** - alongside Czechia, Poland, and Slovakia – Hungary is planning to reinforce its climate – and environmentally related efforts within the group to determine effective and mutually beneficial local and regional policies and measures.

3. Process of Concept Development, Stakeholder Engagement and Public Consultation

The NCDS was based on a wide stakeholder consultation process involving professional and civil society groups and organizations. The responsible entity for the elaboration of the long-term Strategy was the Ministry for Innovation and Technology (MIT), which deeply involved the relevant ministries and other governmental and nongovernmental actors in the process of developing this document. The most important consultation forum within the government was the Interministerial Working Group on Climate Change. The government reached out broadly and inclusively to public and key stakeholders. MIT carried out an online public consultation November 18–25, 2019, which consisted of a survey on the government website targeting all Hungarians. More than 200,000 answers were received, and the proposals contributed to the NCDS. A detailed summary of the public consultation outcomes was shared on the government website.

The Hungarian government adopted a draft version of the present long-term concept in January 2020, which was available on the websites of the government and the European Commission. Based on this draft, MIT continued and broadened the discussion on the NCDS throughout 2020 by organizing the so-called "Climate Breakfasts". Through this online event series, stakeholders from the private sector, financial institutions, and civil society groups including youth organizations provided contributions on the national climate neutrality target and associated challenges, opportunities, and needs. The detailed written proposals of the stakeholders have been incorporated into the final version of the Strategy.

MIT also involved the Global Green Growth Institute (GGGI) as an independent international strategic advisor in the process and utilized GGGI's broad experience in formulating country-level clean and green growth strategies. Under the framework of this cooperation, **three consultation workshops have been organized to validate the modeling results and discuss sectoral policies and priorities.** A comprehensive list of the consultations carried out can be found in Annex 3, whereas a description of the stakeholder engagement and public involvement in the future revisions of the NCDS can be found in Chapter 7.

Stakeholder consultations

(Annex 7 contains the main suggestions for the strategic environmental assessment of the NCDS based on the Government Regulation 2/2005 (I. 11.))

The elaboration of economy-wide and sectoral decarbonization pathways was partly based on different stakeholder inputs:

i) Consultations with the representatives of the private sector and civil society groups were carried out within the framework of the „Climate Breakfasts". This online event-series made it possible for sectoral actors to share their views and best practices. The inputs provided were taken into account during the modelling of low carbon development scenarios of the NCDS.

ii) Under the development of the NCDS, three consultative workshops were organized where different areas of expertise and the academia had the opportunity to share their views of the modelling as well as to validate the low-carbon scenarios.

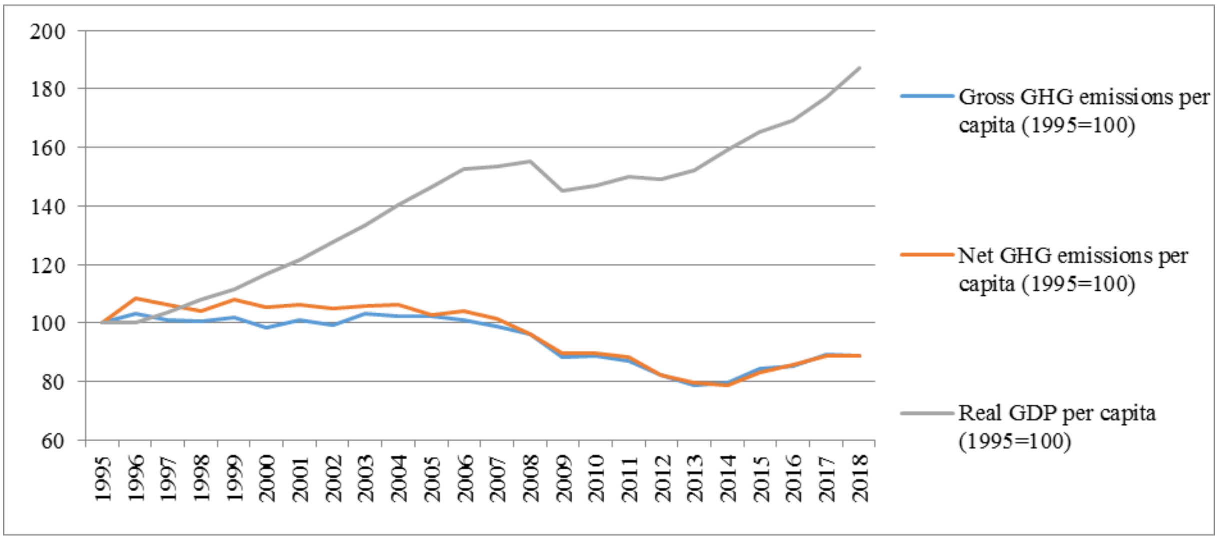
4. GHG Emissions, Policies, and Measures; Their Socioeconomic Impacts and Related Green Growth Opportunities; and Adaptation to the Inevitable Effects of Climate Change

4.1. Economy-wide trajectories for GHG emissions

4.1.1. Historical trends in GHG emissions and their current key sources

According to the latest available data, total GHG emissions in Hungary in 2018 was 63.2 million tons of CO_2eq, excluding the LULUCF sector. At the same time, net emissions, including the LULUCF sector, amounted to 58.6 million tons of CO_2eq. Although the level of emissions did not change significantly between 2017 and 2018, the upward trend of previous years was broken, and there was a decrease of almost 1%, with emissions being 33% below the 1990 level.

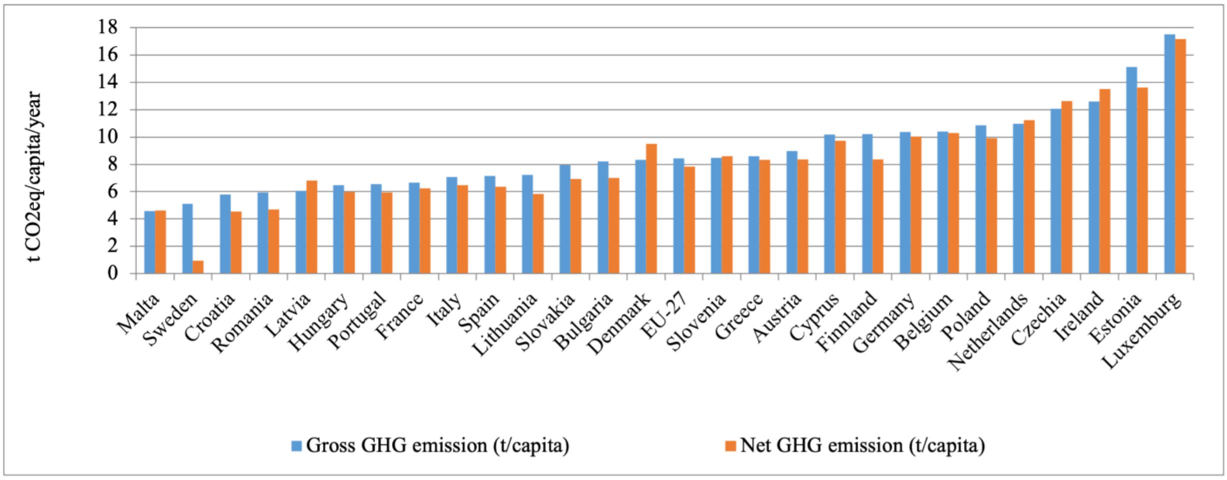
It is a positive trend that after the downturn following the regime change, the country's GDP has been growing steadily, while GHG emissions have not increased overall (i.e., GDP growth and emissions have been decoupled). **The split between GHG emissions and economic development points to the fact that the objectives of economic development and climate protection are not incompatible. (**Figure 7**).**



Source: Eurostat

Figure 7 – Changes in GHG emissions per capita and GDP per capita in Hungary

Gross GHG emissions per capita are 6.5 tons of CO_2eq/capita/year, the sixth lowest in the EU (2018), well below the European average (Figure 8) and the best performance among the V4 countries.



Source: European Environment Agency (EEA), Eurostat

Figure 8 – Gross and net GHG emissions per capita of EU Member States in 2018

The 33% reduction in emissions by 2018 was a consequence of the political and economic regime change of 1989-90, which resulted in a radical decline in production in all sectors of the national economy in the early 1990s. However, after fourteen years of stagnation (1992–2005), GHG emissions significantly decreased by approximately 25% between 2005 and 2013—the global economic crisis of 2008–2009 accounted for approximately 9% of this decrease. The subsequent economic recovery temporarily put emissions on an upward trajectory again from 2013: an increase of 12% was observed until 2017, but total emissions decreased again in 2018 (Table 2).

	1990	1995	2000	2005	2010	2015	2016	2017	2018
Total	93.9	75.3	73.2	75.3	64.8	60.7	61.2	63.7	63.2

Source: Eurostat

Table 2 – GHG emission trends without the LULUCF sector (million tons of CO_2eq/year)

CO_2 accounts for 78–79% of all anthropogenic GHG emissions. The main source of CO_2 emissions is the use of fossil fuels for energy purposes including in the transport sector. Methane is responsible for 12% of emissions, of which its main source is landfills and livestock farms. Nitrogen oxides represent approximately 8% of emissions and are largely derived from the use of fertilizers. The remaining 2% are fluorine gases.

Regarding the distribution of gross emissions by sector (Figure 10), **the energy sector is by far the most responsible for GHG emissions, accounting for 72% in 2018**. However, a positive trend in fossil fuel use is that the share of coal has fallen from 30% to 10% in the last thirty years. **By 2018, transport became the largest emitter, not only within the energy sector but of all subsectors,** accounting for 22% of Hungary's emissions. Road transport dominates emissions within transport, which have risen by almost 40% in the last five years.

IPPU are the second largest emissions contributor, while agriculture is the third largest emitting sector, both of which account for approximately 11% of total emissions. In 2018, 37% of industrial emissions came from the chemical industry, while 19% were due to the use of ozone-depleting substances. The mineral and metal industries contributed 19% and 20% to emissions in the industrial sector, respectively. Other product use (4%) and non-energy use of fuels (1%) accounted for the smallest share.

The share of agriculture in total emissions has not changed significantly in the last 30 years (10–11%). The waste sector accounted for the smallest share of emissions (5%), but overall, this sector alone has increased GHG emissions since 1985 by a total of 7%. The LULUCF sector varies greatly from year to year, mainly due to natural processes. Between 1990 and 2018, the sector removed an average of 3.8 million tons of CO_2eq per year from the atmosphere. In 2018, this amounted to 4.7 million tons, which is about 7% of the gross emissions. This was largely due to forests' sequestration.

4.1.2. Economy-wide decarbonization pathways until 2050

Achieving climate neutrality by 2050 will require significant investment in all sectors of the economy in the coming decades. However**, the medium- and long-term benefits of decarbonizing the national economy outweigh these costs.** Investing in low-carbon technologies and infrastructure will not only contribute to the 2050 climate neutrality goal but also to other national development goals, including environmental sustainability, security of energy supply, and the health and well-being of the Hungarian people.

The lessons of the crisis caused by the COVID-19 pandemic clearly illustrate that it is more economically advantageous to develop prevention strategies than to do costly repairs for the damage caused retrospectively. Early action to reduce GHG emissions is far more beneficial than bearing the material consequences of climate change later.

The identification of different pathways to climate neutrality in 2050 is based on comprehensive integrated modeling across the economy. A wide range of stakeholders have been involved in the modeling and conceptualization process, including experts from ministries and background institutions, as well as representatives of the private sector, covering all sectors. The consultations carried out are presented in Annex 3.
To outline the long-term trajectory, an integrated modeling approach was used to explore the specificities of the sectors and the system-wide and cross-sectoral dynamics of the decarbonization process:

- The **GEM** is an intersectoral model that uses Systems Thinking and System Dynamics as its foundations. This integrated model - which considers the interlinkages existing between populations, economic activity, and environmental outcomes - has been customized for Hungary for the assessment of various economy-wide emission reduction pathways. Therefore, it supports the estimation of the macroeconomic outcomes of decarbonization, including the economic valuation of several social and environmental externalities, in addition to job gains and losses.
- The **HU-TIMES model** was used iteratively with the GEM to model the energy sector and to outline the emission routes of the energy and industrial sectors. TIMES is a bottom-up, partial equilibrium optimization model used to analyze the different pathways of energy flow within the energy subsectors (i.e., transformation, industry, commercial and residential, agriculture, and transport sectors) by taking into consideration the assumptions for exogenous demand for all these subsectors, the current and future available technologies, and the economic environment (e.g., GDP, population, emissions trading system (ETS), and fuel prices). Besides the energy flow, the HU-TIMES model can provide technology and sector-specific information about GHG emissions and the associated additional costs needed to achieve the goals defined in different alternative scenarios.

Further details on modeling, including all assumptions for the design of sectoral and economy-wide emission pathways, are provided in Annex 6.

Each economic sector has different emission reduction potential, depending on the availability and associated costs of low and zero and net negative emission technologies. Given the differences in the structural and technological development of each sector, it is virtually impossible to achieve absolute zero emissions in all sectors. Therefore, a system-wide, integrated, and cross-sectoral approach has been used in the design of emission routes.

The modeling not only estimated the costs needed to reach the climate neutrality target by 2050 but also explored the macroeconomic impacts of decarbonization pathways, including the effects on GDP growth, employment, and government revenues. In addition, the analysis considered important benefits of emission reductions, such as resource and material savings, reduction of negative transport externalities, positive health effects, and increased productivity.

Three scenarios for GHG emissions up to 2050 have been developed:

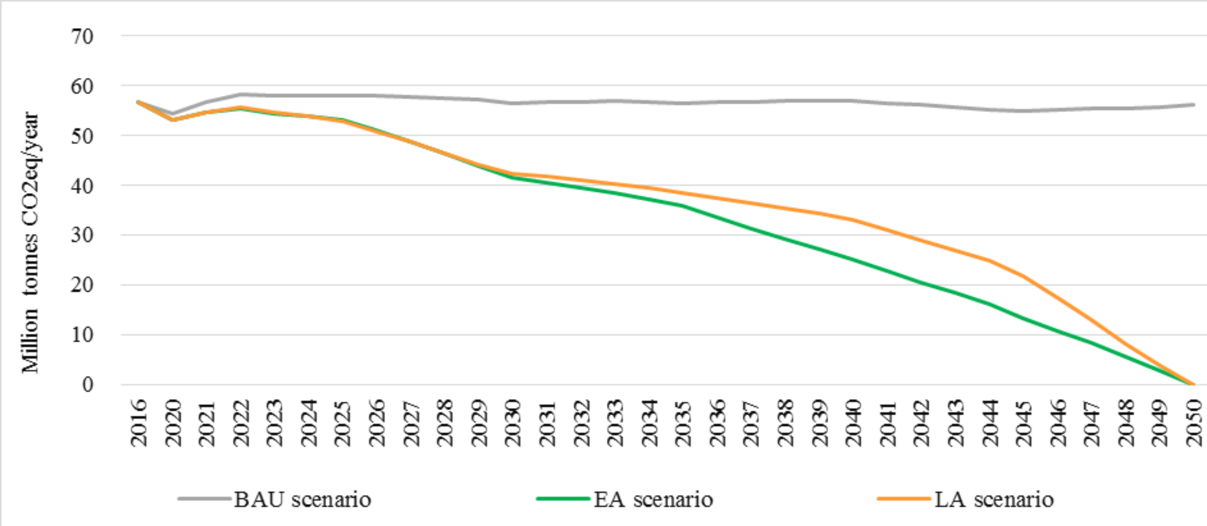
a) **BAU:** The emission trajectory of the scenario follows current trends. The scenario does not include energy efficiency, renewable energy, or GHG emission reduction targets for 2030 and 2050, respectively, and therefore does not include the targets set in the NECP and the new NES. Current trends have been considered in all sectors, without further efforts to reduce emissions.

b) **LA climate neutrality scenario:** This scenario aims to achieve net climate neutrality by 2050 by reducing emissions in the energy sector at a slower pace by 2045 and then with an increased effort until 2050. This allows the lower cost levels of low and zero emission technologies to be exploited. The scenario assumes that, in line with the targets set in the climate act, final energy consumption could reach a maximum of 785 PJ in 2030, with the share of renewable energy increasing to at least 21%. After 2030, non-waste sectors will be on the lowest cost trajectory toward climate neutrality, which will result in accelerated emission reductions by the end of the period, due to the postponement of investments pending on a decrease in technology costs. In the case of waste management, the model assumes a higher level of ambition by 2030 to meet the EU targets for reducing landfill use (circular economy).

c) **EA climate neutrality scenario**: the EA approach envisages achieving climate neutrality by 2050, while considering the short- and medium-term benefits of job creation and the reduction of environmental externalities, the economic potential of the first mover, improved productivity, and higher GDP growth. The scenario assumes that Hungary's final energy consumption in 2030 will be a maximum of 734 PJ, and that renewable energy penetration will reach 27%. The emission reduction trajectories for industry, LULUCF, waste management, and agriculture are the same as in the LA scenario. Between 2030 and 2050, emissions will follow a linear trajectory to reach net zero emissions. In both the LA and EA scenarios, CCUS technologies will become commercially viable in the energy and industrial sectors after 2030.

For all three scenarios, the same demographic trends were identified, while GDP values were estimated endogenously by the GEM model.

The projection of GHG emissions under the three scenarios examined is illustrated in Figure 9.



Source: Eurostat, projection based on own modeling result

Figure 9 – Expected change of total annual net GHG emissions for the whole economy under the three scenarios examined (CO_2eq/year)

The cost-benefit analysis of the scenarios up to 2050 found that the EA scenario **clearly has several economic and employment opportunities,** which need to be exploited in the context of the economic stimulus following the COVID-19 crisis:

- The **additional investments** required compared to the BAU scenario amount to **approximately HUF 24.7 billion** in this scenario. These investments will be needed mainly to build clean energy production capacities, close end-of-life power plants and industrial facilities, renovate existing buildings and build new energy-efficient buildings, and develop electric transport infrastructure. The transformation of the waste management system, the acceleration of the introduction of the circular economy, and the introduction of new sustainable agricultural practices will also require significant investments.

- At the same time, the early implementation of investments will result in **higher GDP and government revenue and avoided costs** by 2050 and a greater degree of avoiding negative environmental externalities than in the case of a later implementation of these investments.

- An important aspect is that the **early implementation of investments can serve as an incentive for recovery during the economic crisis caused by the COVID-19 pandemic by creating thousands of new and green jobs and increasing the well-being of the Hungarian people.**

- Although the costs of financing and capital are currently low, channeling public and private resources toward green investment is more important than ever since tackling climate change is an urgent task.

- In addition, accelerating the green transformation will allow Hungary to reduce material costs (including fuel costs) and imports, thus improving the trade balance and freeing up resources for other important purposes as well as increasing security of supply.

Subchapter 4.3 and Table 11 detail green employment opportunities and socioeconomic benefits of the EA and LA scenarios.

As a result of the modeling, the following conclusions can be drawn:

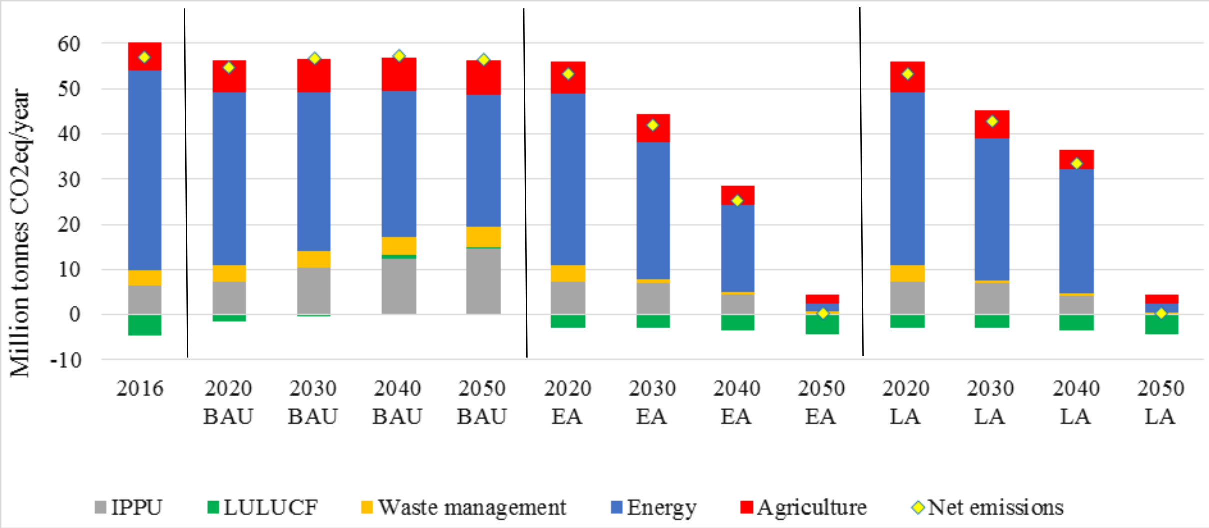
- By 2050, the net zero emission target will be achieved using existing and developing technologies that are not yet or are only partially marketable. It is estimated that CCUS and hydrogen technologies will gradually gain ground after 2030;
- Each sector must contribute to the goal of climate neutrality, depending on its own reduction potential, associated costs, and technological readiness; and
- Increasing the domestic GHG absorption potential is essential for achieving the country's climate neutrality goal.

The emission reduction trajectories of the two climate-neutral scenarios will start to diverge from the mid-2020s; by 2030, the difference will exceed 800,000 tons of CO_2eq. The larger reduction is the result of the EA scenario. In the case of early action, this requires greater efforts, which can be explained by the fact that increasing investments has a positive effect on the country's GDP. This in turn boosts demand from end-user segments, such as demand for travel or household appliances, thus increasing energy consumption. By 2030, GHG emissions will decrease significantly in both scenarios, by 54.4% (EA scenario) and 53.5% (LA scenario), based on a baseline of 91.33 million tons of CO_2eq.

For both the LA and EA scenarios, three constraints have been applied for 2030: a GHG, energy efficiency, and renewable energy constraint. For both scenarios, **the most significant constraint is the scale of expansion of the renewable energy use**: at least 21% penetration should be achieved under the LA scenario and at least 27% penetration is expected under the EA scenario. This difference results in a significantly higher use of renewable energy in the EA scenario, leading to lower GHG emissions. Based on the modeling results, the EA scenario has a renewable electricity production that is 1 terawatt-hour higher than in the LA scenario. This does not replace internal fossil fuel production but lowers the import ratio, so its GHG balance can be considered “neutral” for Hungary.

From 2030 to 2045, the two emission trajectories sharply diverge, as the EA scenario follows a gradual and steady emission reduction trajectory, while the LA scenario sets a slower rate of reduction. After 2045, according to the LA scenario, a sharp decrease in emissions can be observed, reaching climate neutrality by 2050. The EA scenario will integrate earlier CCUS technologies and hydrogen use into the power generation and industrial sectors while accelerating the electrification of the economy and transport. Fossil fuels are being phased out of the electricity mix, resulting in a steep reduction in emissions from the energy and transport sectors.

The sectoral distribution of GHG emission reductions under different scenarios is illustrated in **Hiba! A hivatkozási forrás nem található.**.



Source: Eurostat, projection based on own modeling result

Figure 10 – Sectoral distribution of net GHG emissions under the three scenarios examined (CO_2eq/year)

The following trends and changes need to be facilitated in all sectors of the economy while exploiting the benefits of green economic development and employment:

- Promotion of **energy efficiency** through information and awareness-raising campaigns.
- Acceleration and expansion of **energy efficiency investments**[11], particularly through the energy efficiency obligation scheme—especially in the residential and commercial sectors.
- Significant investments will be needed to **electrify** the economy, especially in the transport, residential, and commercial sectors. One of the main conditions for the electrification of the economy is the modernization and climate-friendly transformation of the energy sector.
- Further investment will be needed in the **development of CCUS technology**, **increasing the utilization of renewable energy and energy storage systems**. Given carbon phase-out efforts, new investments in fossil fuel-based technologies and industries run the risk of rapidly depreciating assets.
- In addition to the electrification of the **transport** sector, the expansion of the use of second-generation (or advanced) biofuels and carbon-free (or low-carbon in the transition period) hydrogen, the phasing out of LPG by the end of the period, and fuel efficiency will contribute to the decarbonization and modernization of the sector.
- In the **agricultural** sector, investments will be needed mainly to reduce fertilizer use; to increase the use of precision farming, automation, and digitization; to manage organic manure more efficiently; and to increase feed, irrigation, and energy efficiency.
- Significant investments will be needed in the **waste** sector to drastically reduce landfilling. About 90% of the sector's emission reductions come from reducing landfills,

[11] In the energy efficiency obligation system, the implementation of energy efficiency targets is achieved by involving the market, by shared burdening the companies selling electricity, gas and fuel, as a result of which the public repays the renovation costs not in one amount, but for several years.

diverting waste streams, and improving treatment methods. Further investments will be needed to reduce the amount of industrial waste, improve municipal waste management, and prevent waste generation. Given the nature of waste management activities, reducing the sector's emissions will also require investments in other sectors (e.g., in the transport sector due to waste collection).

- In the **IPPU sector**, the development of production/manufacturing processes, greater material efficiency, the introduction of a circular economy, alternative raw materials, and new and efficient tools are needed to nearly eliminate emissions.
- There is also a strong need for investment in the **LULUCF** sector to maintain and increase post-2030 CO_2 sequestration; in particular, measures to improve the adaptive capacity of forests, reduce logging in the medium term, and increase afforestation in the long term. In line with the requirements of sustainable forest management, emphasis should be placed on maintaining stock structures and management models with the best possible CO_2 balance (in terms of spatial and age structure), and active interventions should help forest stocks to survive, preserve, and develop their natural level despite the effects of climate change.
- **Research, development, and innovation** will be a priority to achieving the energy and climate goals. Through the continued development of new technologies and processes, as well as their market introduction, a degree of cost reduction can be achieved to greatly help the spread of clean technologies.
- The **education and training** of professionals capable of developing and/or applying new technologies and processes is also key.

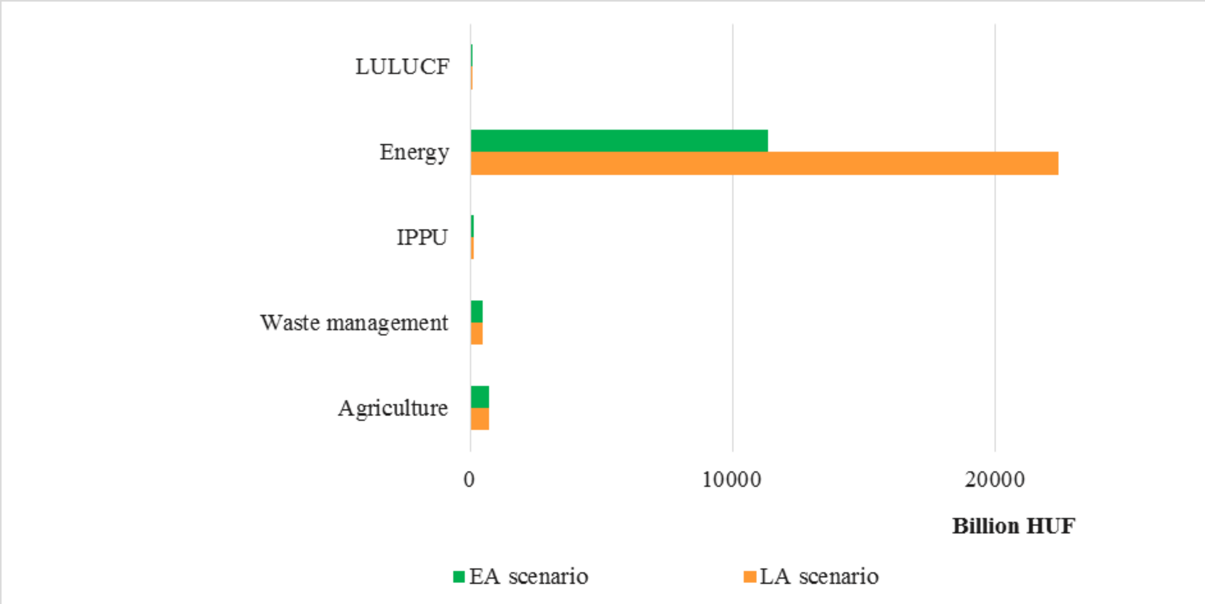
Sector	**Reduction vs. 1990 (%)**
Energy	-98%
Industry (IPPU)	-98%
Agriculture	-79%
LULUCF	-71%[12]
Waste	-87%
Total	**-100%**

Source: own modeling calculation

Table 3 – GHG reductions of sectors by 2050 compared to 1990 levels in the EA scenario (%)

Achieving climate neutrality by 2050 will require significant additional investment in all emitting sectors (Figure 11).

[12] Increase in net absorption



Source: own modeling result

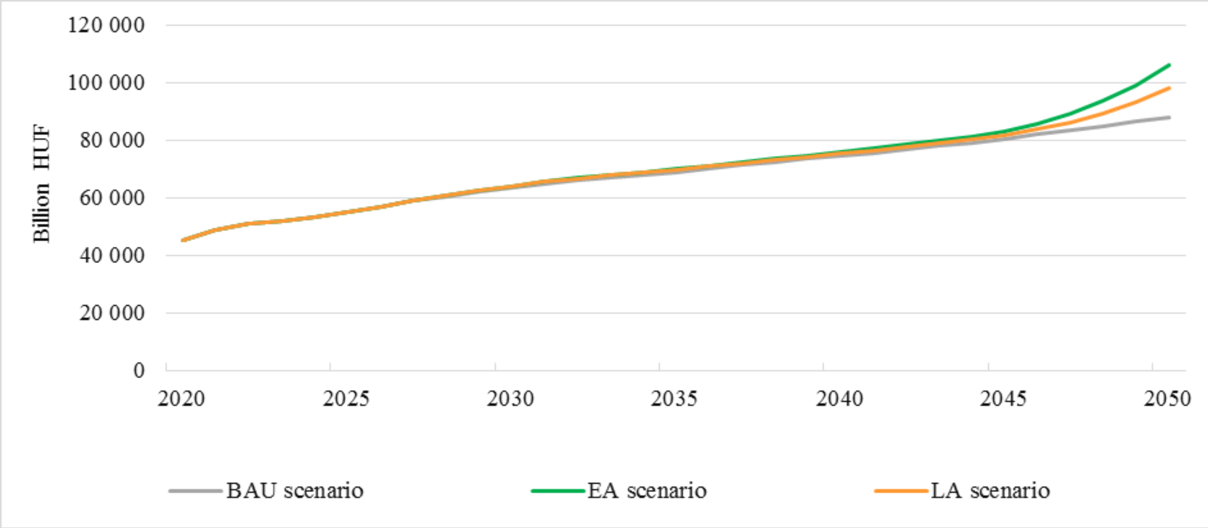
Figure 11 – Additional investment needs by sector in the LA and EA scenarios compared to the BAU scenario

In the case of the EA scenario, the costs increase to approximately **HUF 24.7 billion** compared to the BAU scenario. The annual additional investment requirement is about **4.8% of GDP** in the EA scenario.

According to the projections, the complete decarbonization of the Hungarian economy will also generate significant **avoided costs and economic and social benefits**. Significant material savings can be achieved from less energy and fertilizer use, resulting in a reduction in material costs of approximately HUF 2.4 billion. Investments and avoided costs lead to **economic growth and job creation**, which exceeds the economic growth and job creation potential of the BAU and LA scenarios.

The early investments defined in the EA scenario, as well as the gradual and steady reduction in emissions, are projected to result in 20.7% higher GDP by 2050 compared to the BAU scenario. Between 2020 and 2050, the average annual GDP growth will be 0.56% higher than in the BAU scenario. These projections are in line with EU simulations, which have estimated impacts between -0.4% and + 0.5% of GDP/year to reach the 55% emission reduction target by 2030.

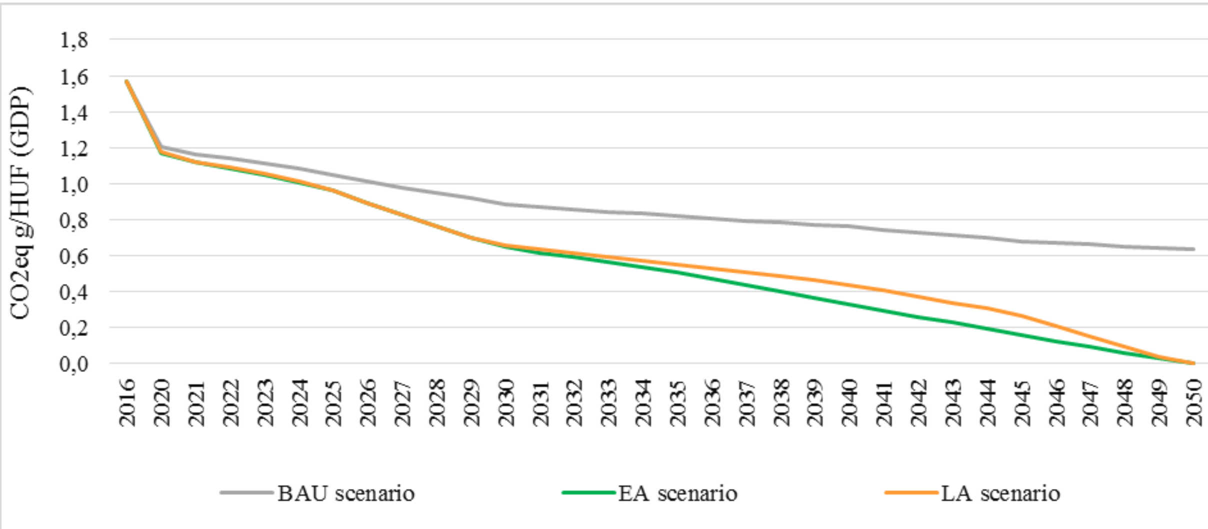
According to the EA scenario, the cumulated surplus GDP amounts to approximately HUF 19.8 billion, and the government revenues are forecasted to increase by about HUF 11.1 billion cumulatively between 2020 and 2050 (**Hiba! A hivatkozási forrás nem található.**).



Source: own modeling result

Figure 12 – Real GDP developments under the three scenarios examined

According to the model, economic growth will pick up after 2028 due to significant additional investment. By 2034, the trajectory of GDP and GDP growth will be similar in all three scenarios. After 2035, GDP under the EA scenario will grow faster than in the other two scenarios. The EA scenario estimates an average annual GDP growth rate of 2.9% over the period 2021–2050.[13] For the BAU scenario, the expected average growth over the same period is 2.5%. In addition – as shown in **Hiba! A hivatkozási forrás nem található.** – according to the EA scenario, the carbon intensity of the Hungarian economy will gradually decrease from 1.2 tons of CO_2eq/million HUF in 2020 to zero in 2050, while according to the BAU scenario, a carbon intensity of 0.6 tons of CO_2eq/million HUF is expected by 2050.



Source: Eurostat projection, own modeling result

Figure 13 – Carbon intensity of the Hungarian economy under the three scenarios examined

[13] Value calculated on the basis of the arithmetic average of annual real GDP growth rates projected for the period 2021-2050. A common method for calculating the average growth rate is the geometric average, which can be used to estimate an increase of 2.6% between 2021 and 2050. (See the UN-ESCAP factsheet available at https://www.unescap.org/sites/default/files/Stats_Brief_Apr2015_Issue_07_Average-growth-rate.pdf)

According to the system dynamics model calculations, the decarbonization of the national economy creates new jobs in the analyzed sectors. The macroeconomic effects of investing in the green transition will spill over, leading to higher GDP and more green jobs compared to the BAU scenario. The EA scenario estimates that investments in the decarbonization of the energy sector, energy efficiency measures, waste management, bus transport, and reforestation could create nearly **183,000 new** jobs by 2050 compared to the BAU scenario. Job creation resulting from the greening of sectors significantly offsets the loss of jobs in the waste management and fossil fuel-based industries. Through appropriate retraining programs and the efficient use of the EU’s Just Transition Fund resources, the Hungarian economy can benefit from the green transition.

The role of energy saving is outstanding

The largest potential for energy savings is in the **residential sector**, due to the cost-effective renovations to be carried out mainly under the energy efficiency obligation scheme as well as the favorable energy consumption indicators of newly built dwellings. Primary energy demand is further reduced by better energy efficiency in modern household appliances.

In addition to the residential sector, a higher rate of energy savings can be achieved in the **industry** sector; however, the results of the two climate-neutral scenarios (mainly in the case of the EA scenario) show an increasing trend in energy consumption compared to the BAU scenario. This is because higher investment activity has a positive effect on GDP growth, strengthening the performance of industrial sectors as well. For this reason, higher final energy consumption (540 PJ) is expected in the EA scenario for the 2050 target date than in the LA scenario (485 PJ). The impact of higher GDP on final energy consumption is particularly pronounced when we consider the more ambitious 2030 energy savings target in the EA scenario. This is also the reason why there is no major difference in the final energy consumption values in 2040 between the two scenarios.

In the case of the **transport sector**, the EA scenario also shows a smaller increase in energy consumption compared to the values seen in the LA scenario by 2050, which can also be explained by faster GDP growth. In the intervening years, however, lower energy consumption is expected in the EA scenario, as it is most cost-effective to reduce energy consumption in the transport sector in addition to buildings, and this is not offset by the GDP effect. Due to the large-scale fuel shift and modal shift, by 2050 the energy consumption of the sector will only slightly exceed the 2016 level.

Renewable energy-based energy use and the rise of carbon-free hydrogen play a key role in the decarbonization of transport; technologies using these energy sources are more efficient than those currently used in internal combustion engines. Prioritizing public transport over private transport will further reduce the primary energy demand of the transport sector. In contrast to the smaller increase in energy consumption in the EA scenario, in the LA scenario, due to the lower GDP impact, the 2050 value will result in 90% of the 2016 value.

The share of renewable energy will expand significantly

The high share of renewable energy in 2050, which is close to 90%, is explained by the combined effect of several factors. The use of renewable energy is greatly increased by the production of hydrogen based on electricity from electrolysis technology and increasingly from renewable sources, which reduces the use of natural gas. In addition, due to the high degree of electrification, which occurs in all areas of the energy sector—including the building, transport, and industrial sectors—more than 10 gigawatts (GW) of renewable power plant capacity are needed, which requires a similar amount of energy storage (battery) capacity for smooth operation.

Moreover, the high uptake of biomass-based electricity generation with CCUS technology will further increase the share of renewable energy. In addition to climate-friendly (carbon-free) electricity generation, the use of this technology is also needed because it has the only additional removal capacity. While based on the current methodology, biomass accounts for zero CO_2 emissions, with CCUS technology, we can expect negative emissions.

An increase in the use of renewable energy will greatly contribute to a large decrease in energy imports, thus contributing to an increase in energy security. This affects all areas of the energy sector: the electricity sector, oil consumption, and the reduction of natural gas import demand through the reduction of natural gas consumption. Most renewables will come from solar power, biomass, and biofuels.

4.1.3. Indicative milestones

To reach the 2050 net zero GHG emissions target, indicative milestones can be set for the EA and LA scenarios, based on the modeling results, showing the stages to be reached by 2030 and 2040. These milestones also provide an indication of the extent to which net zero emissions in 2050 are energy efficiency indicators and the proportion of renewable energy that can be achieved in an optimal, cost-effective way relative to gross final energy consumption.

As shown in Figure 9, there is an accelerating net GHG emission reduction trajectory for the LA scenario, in which case the 35.9% GHG emission reduction in 2018 will increase to 54% by 2030 and 64% by 2040. In contrast, in the EA scenario, a more balanced, linear GHG emission reduction trajectory has been identified, in which case the rate of reduction in 2040 will already reach net 73%.

In the case of the EA scenario, the share of renewable energy in gross final energy consumption also shows a more balanced increase. The renewable rate of 13.3% in 2017 will double by 2030 and then remain at the 2040 level (25.1%). In contrast, in the LA scenario for 2017 and 2030, growth is less than 8 percentage points.

Compared to the final energy consumption of 775 PJ in 2017, there is an indicative energy efficiency target of 5.3% by 2030, almost 15% by 2040, and more than 30% by 2050 for the EA scenario. In contrast, in the LA scenario, there will be an increase of 1.2% by 2030, then 14.5% by 2040, and 37.4% of energy saving demand by 2050 to achieve climate neutrality.

4.2. Sector-specific pathways, policies, and measures

The cost-benefit analysis of the scenarios up to 2050 (Subsection 4.3) reveals that the BAU scenario does not meet the increased 2030 GHG emission reduction target or the 2050 climate neutrality target set in Act no. XLIV of 2020 on Climate Protection. Based on the cost-benefit analysis performed, the net benefit of the EA scenario exceeds the LA scenario; therefore, this subsection focuses only on the comparison of the BAU and EA scenarios.

4.2.1. Energy

Strengths	**Weaknesses**
Reduction of operating costs Decreasing and more sustainable use of biomass Reduction of external costs (e.g., air pollution) High share of carbon-free electricity in electricity generation	Significant additional investment costs Limited technology choice to achieve the 2050 climate neutrality target
Opportunities	**Threats**
Innovation in electricity storage Hydrogen technology CO2 capture, utilization, and storage Favorable conditions for the utilization of solar energy and geothermal energy	Uncertainty in CO2 capture, utilization, and storage Problematic integration of a higher proportion of hydrogen into the gas network The level of low or zero emission technologies costs does not decrease

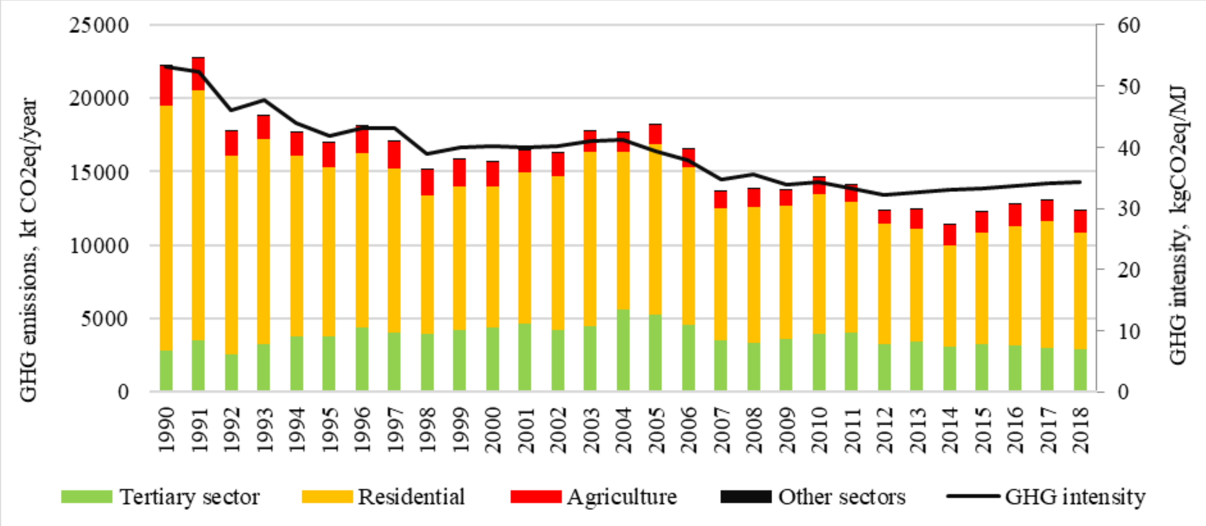
Table 4 – SWOT analysis of the Energy Sector

Developments and main trends in past emissions

In Hungary, as in the world in general, **the energy sector is the largest GHG-emitting sector**. In 2018, the sector's GHG emissions exceeded 45.5 million tons of CO_2eq, which is 72% of the total Hungarian GHG emissions (**Hiba! A hivatkozási forrás nem található.**). **Of these emissions**, **28.8% came from electricity and district heating, 30.6% from transport, and 11.7% from industrial energy consumption**. Within the energy sector, a significant share of the emissions can be attributed to the energy consumption in buildings and the agricultural sector (27.1%), while the remainder are fugitive emissions (1.8%).

Emissions related to energy consumption in the residential, service, and agricultural sectors have decreased significantly since the regime change in 1990, partly due to energy efficiency gains and the use of fossil fuels with lower GHG intensity. While households and the tertiary sector were associated with significant coal and oil consumption in the early 1990s, the use of these fuels declined substantially after the democratic transition. In the case of the retail and tertiary sector in general, GHG emissions fell steadily between 1990 and 2007; from 2007 onward, they came to a near stagnant trajectory.

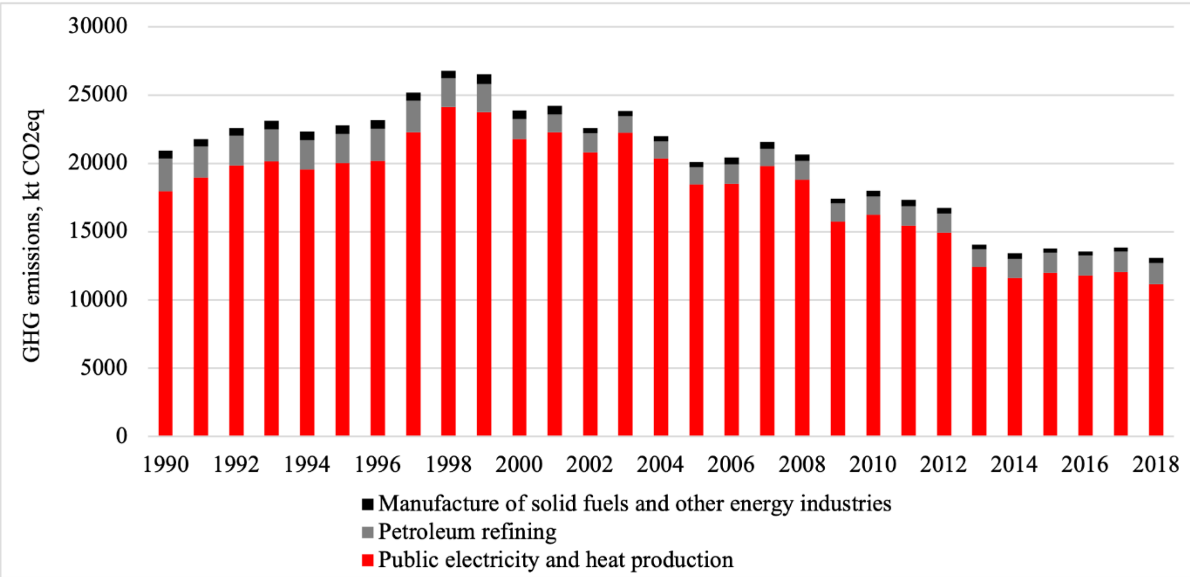
The difference between individual years was mainly caused by the fluctuating energy demand of heating. During this period, the GHG intensity did not change significantly, stabilizing at 37–39 kg/MJ.



Source: EEA and Eurostat

Figure 14 – GHG emissions from energy consumption in the residential, service, and agricultural sectors (kt CO_2eq) and the change in GHG intensity (kg CO2eq/MJ), 1990–2018

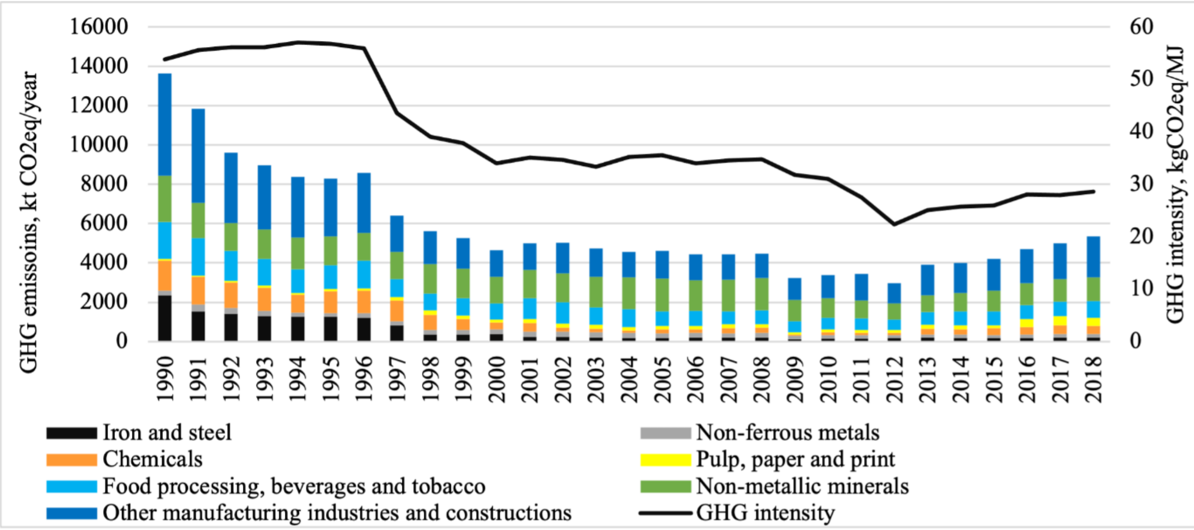
In contrast to other sectors, *GHG emissions from electricity and district heating* (***Hiba! A hivatkozási forrás nem található.***) started to increase in the years following the regime change and peaked in the late 1990s. Subsequently, with the decline in fossil electricity production (mainly based on coal and lignite), emissions started to decrease significantly until the early 2010s. In the last five to six years, GHG emissions from electricity and district heating production have stagnated between 12–14 million tons of CO_2eq/year, of which about 5–6 million tons come from the country's last lignite-based power plant, the Mátra Power Plant.



Source: EEA and Eurostat

Figure 15 – GHG emissions (kt CO_2eq) from the electricity and district heating sector and from the other energy industries, 1990–2018

In the years following the 1990 regime change, in parallel with the decline of industrial facilities, especially heavy industry, the energy consumption of the industrial sector also decreased, and as a result, *the GHG emissions related to energy consumption of industry* declined as well (**Hiba! A hivatkozási forrás nem található.**). While GHG emissions from industrial energy use were around 14 million tons at the time of the regime change, they have fallen below 10 million tons of CO_2eq/year in a few years. The decrease in GHG intensity can be explained by the fact that the industrial subsegments for the productions that decreased significantly used mainly coal and crude oil. The decline in GHG emissions continued until the early 2000s, and then the economic crisis of 2008-2009 resulted in another decline. Overall, however, the emissions have increased over the last few years, with GHG emissions from energy use in the industrial sector increasing by 80% in the last six years, explained by the rapid expansion of industrial production.



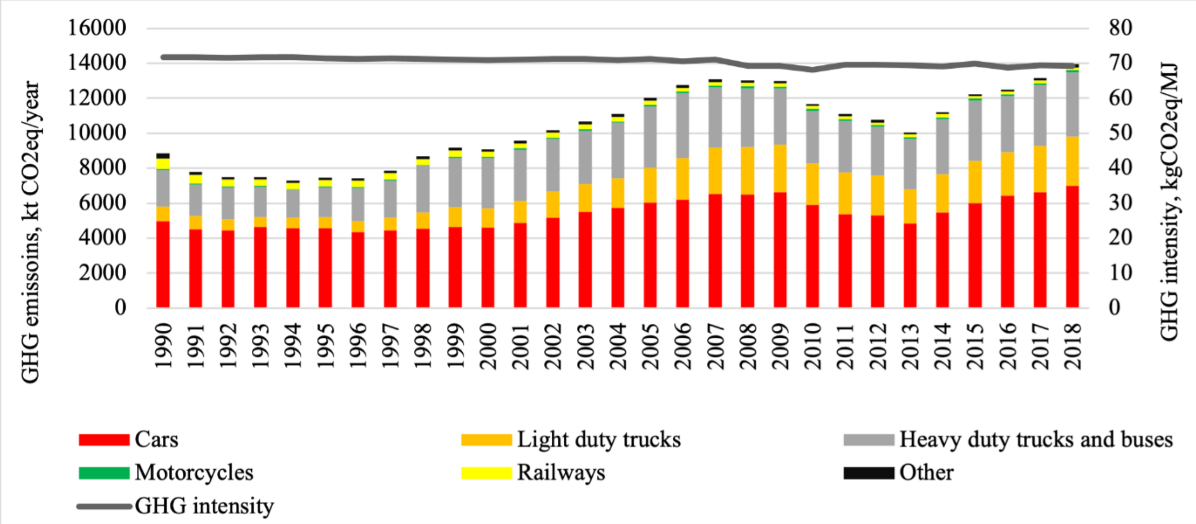
Source: EEA and Eurostat

Figure 16 – GHG emissions (kt CO_2eq) and GHG intensity (kg CO_2eq/MJ) from industrial energy consumption, 1990–2018

In Hungary, the transport sector is responsible for 20% of all GHG emissions (**Hiba! A hivatkozási forrás nem található.**). According to Eurostat data, in 2018, GHG emissions from transport were 13.9 million tons of CO_2eq/year, of which 92.8% were road, 5.1% aviation, 1.1% rail, 0.1% water transport, and 1% related to other transport.

Transport emissions have increased by 31.4% since 2013, and without significant policy intervention, further growth is expected soon. As such, reducing GHG emissions from this sector in Hungary will be one of the biggest challenges in the short term. The cause of this expansion is due to the higher level of motorization in connection with increases in income, economic development of the Central and Eastern European regions, and growth in road freight transport, especially transit traffic through Hungary.

Considering domestic emissions, it is necessary to pay attention to road and rail transport in long-term planning, which together accounted for 88% of passenger transport performance and 84.3% of freight transport performance in Hungary in 2017. In addition, aviation must be considered because foot traffic at the Budapest Liszt Ferenc International Airport increased from 8.5 to 14.9 million people between 2013 and 2018.

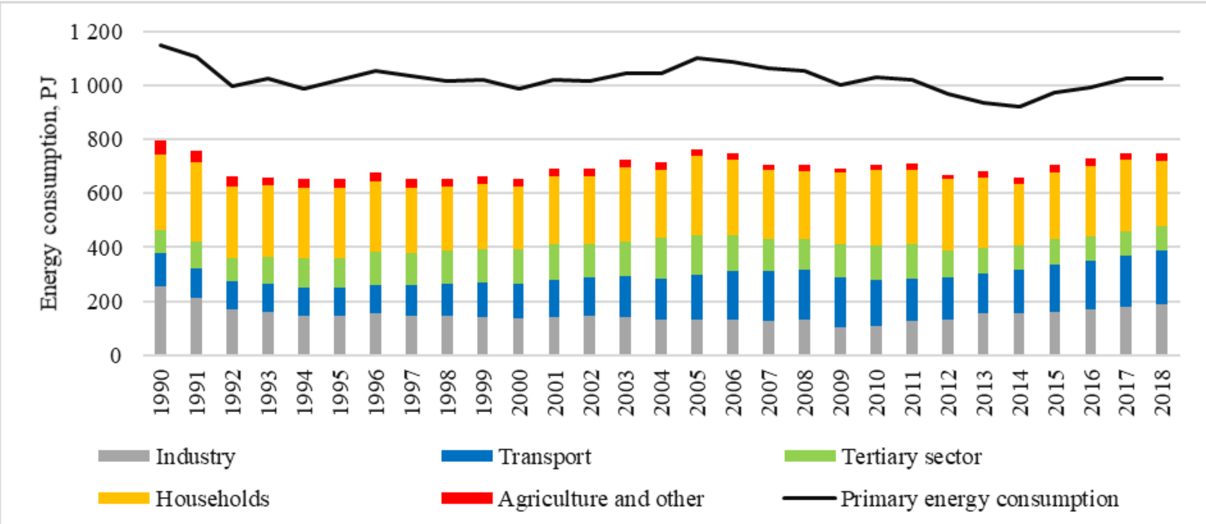


Source: EEA and Eurostat

Figure 17 – GHG emissions from transport energy consumption (kt CO_2eq) and GHG intensity (kg CO_2eq/MJ), 1990–2018

Past trends of final energy consumption

Final energy consumption has remained relatively stable over the last three decades, with smaller changes than in the case of GHG emissions (**Hiba! A hivatkozási forrás nem található.**).



Source: Eurostat

Figure 18 – Composition of final energy consumption and the change in primary energy consumption, 1990–2018 (PJ)

The final energy consumption fell from 800 PJ in 1990 to 650 PJ in a few years, due to the collapse of the industry. It remained at this level until the early 2000s, then increased due to strong growth in the transport sector, peaking at around 760 PJ in 2005. As a result of energy efficiency investments and energy savings in the household and service sectors, final energy consumption decreased to 660 PJ by 2014. The recent years are marked by new growth due to increased energy consumption in the industrial and transport sectors. The primary energy consumption has followed a similar trajectory as final energy use in recent decades.

Actions needed in the energy sector to achieve net zero GHG emissions at the national level

In order to meet the 2050 net zero GHG emissions at the national level, emissions from the energy sector must be reduced to at least 2 million tons. This requires improving energy efficiency and increasing electrification, as well as using CCUS technology, hydrogen technologies, and modern bioenergy technologies.

These requirements entail a marked transformation of the fuel composition of the energy sector. The significant reduction and phasing out of the role of natural gas in certain sectors (e.g., households) will be decisive. Due to the high degree of electrification, significant interventions will be required on the electricity generation side as well. There is a need for a large-scale deployment of clean, renewable technology with a capacity of more than 10 GW to meet the significant increased demand for electricity by mid-century. As intraday, variable (weather-dependent) renewable electricity generation and daily peak consumption do not match, significant electricity storage (primarily battery technology) capacities will need to be built. Consultations with industry experts have confirmed that energy storage flexibility is a key requirement for the twenty-first-century electricity system.

The annual change in renewable energy production is not in line with the annual consumption profile. For this reason, it is equally important to promote the use of technologies that can store large amounts of energy for a longer period (especially power-to-gas (P2G) technologies) in Hungary.

One of the cornerstones of decarbonization is hydrogen

The HU-TIMES model distinguishes between different types of hydrogen production:

- Grey hydrogen: it is produced from natural gas, so it has a significant GHG emission impact.
- Blue hydrogen: it is produced from natural gas, but it is also associated with CCUS technology. Although this production method has a significantly better GHG balance than grey hydrogen, as CCUS is not 100% efficient, i.e., it is not able to capture the total CO2 emissions, it is considered a net pollutant in terms of GHG emissions.
- Carbon-free or low-carbon hydrogen: produced in a carbon-neutral way or from low-carbon electricity

Currently, hydrogen is transported in a compressed gas or liquid state. For large quantities, pipeline transport may be the ideal, for smaller quantities, road, rail and water transport seem to be a better alternative.

Hydrogen can be transported by pipeline in two ways. On the one hand, through a dedicated hydrogen network, the construction of which involves significant investment costs, and by being integrated into the natural gas network. In the latter case, further studies are needed to determine the maximum level of safe incorporation, the technical possibilities and the related development needs.

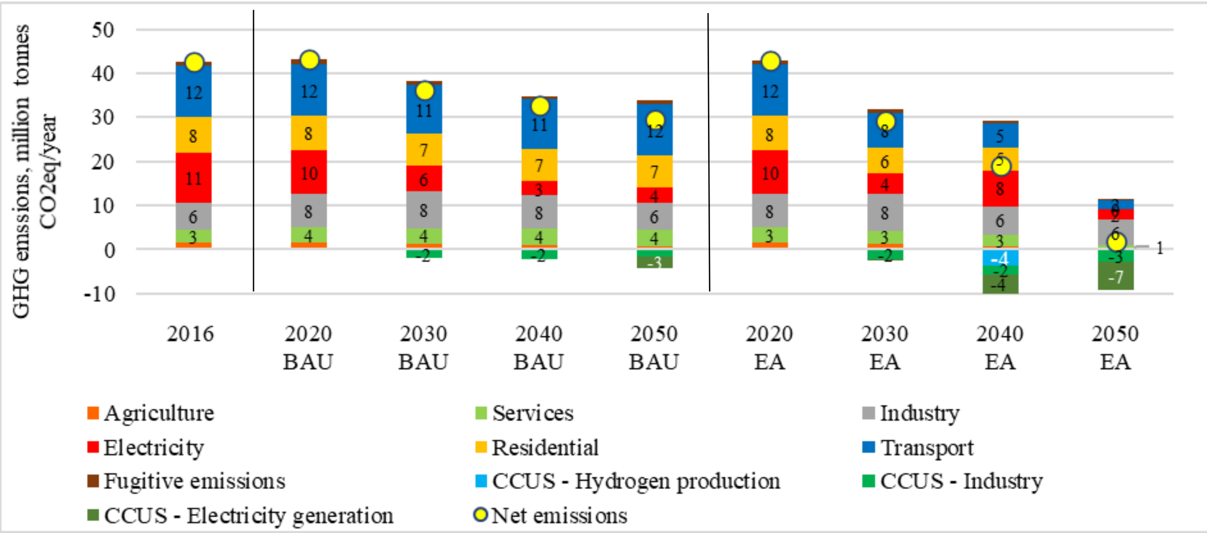
Dedicated hydrogen networks should be built primarily in the direction of large industrial facilities (or even hydrogen production can take place there), while blending should be used in a segment where building a hydrogen network would be very costly (e.g. residential or other geographically dispersed energy consumers).

Change in GHG emissions

Achieving net zero greenhouse gas emissions at the national level is possible if emissions from the energy sector fall to at least 2 million tons of CO_2eq from the current value of 40 million tons; that is, a 96% reduction is needed (**Hiba! A hivatkozási forrás nem található.**).

CCUS technology is essential to achieve the goals. With the current knowledge and technologies, it would not be possible to reduce GHG emissions in the energy sector to the required level without carbon sequestration. In many subsectors—industry, transport, and others (such as carbon leakage and agricultural energy use)—full decarbonization cannot be achieved without CCUS. The CCUS technologies typically only enter the energy system in the 2030s, and possibly the 2040s, as there are usually cheaper solutions to tackle GHG emissions.

Under the BAU scenario, GHG emissions will decrease slightly for the energy sector but will still emit almost 30 million tons of CO_2eq in 2050, a reduction of only about 57% compared to the base year 1990. The largest decrease is in the energy sector, and bioenergy with CCUS also appears in the BAU scenario, due to the high CO_2 quota price.



Source: Eurostat, own modeling result

Figure 19 – GHG emissions in each scenario, 2016–2050 (million tons of CO_2eq/year)

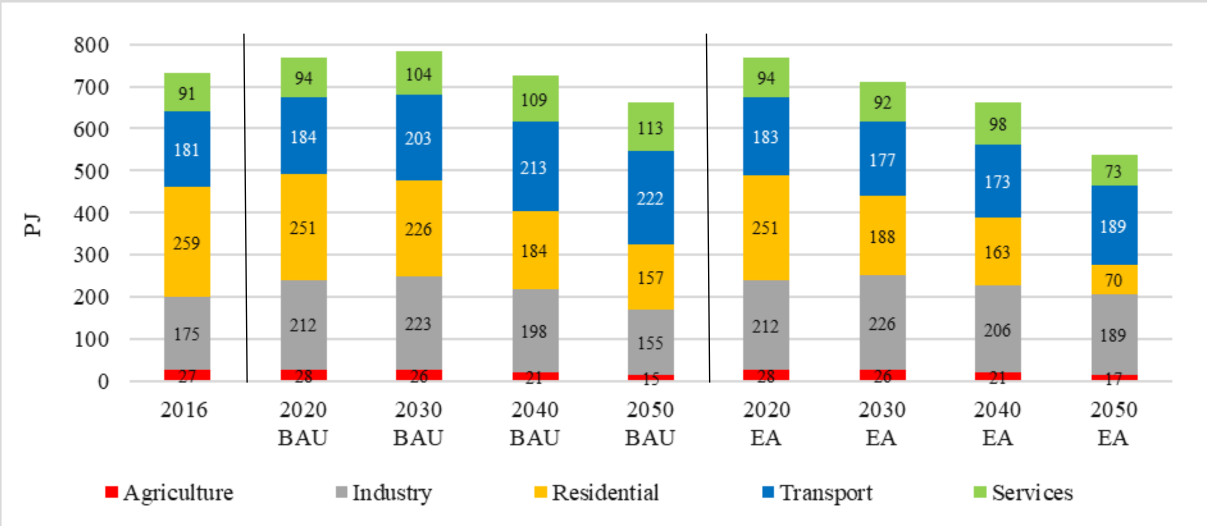
Changes in final energy consumption by sector

The household subsector clearly has the greatest potential for energy savings (**Hiba! A hivatkozási forrás nem található.**). Even in the case of the BAU scenario, the energy consumption of households decreases significantly, due to the substantially lower energy consumption of new appliances, newly built dwellings, and renovations implemented primarily under the energy efficiency obligation scheme. These will result in a decrease of energy consumption from 260 PJ to below 160 PJ by 2050, even under the BAU scenario. The decrease is even more significant in the EA scenario, where by 2050 the energy consumption of households will drop to 70 PJ, which is only 26% of the consumption of the base year.

The energy consumption of the industrial sector develops differently between the examined scenarios. In the BAU scenario, GDP growth is accompanied by an increase in energy consumption at the beginning, followed by energy efficiency investments, and a steadily declining trend from 2030 onward. In the EA scenario, the trend is identical until 2030; thereafter, energy consumption will decrease less than in the BAU scenario. This is not due to a lack of energy efficiency investments, but because the EA scenario will lead to faster

GDP growth, which in turn will be accompanied by an increase in industrial production and thus energy consumption. Faster economic growth is due to the significantly higher level of investment activity in the national economy in the climate-neutral scenario.

The service and transport sectors follow similar trajectories in the two scenarios. If no climate targets are set, energy consumption in both sectors will increase slightly, while in the EA scenario it will decrease by 10–20% compared to current levels, due to energy efficiency investments and more efficient fuel composition.



Source: Eurostat, own modeling result

Figure 20 – Composition of final energy consumption by sector in each scenario, 2016–2050 (PJ)

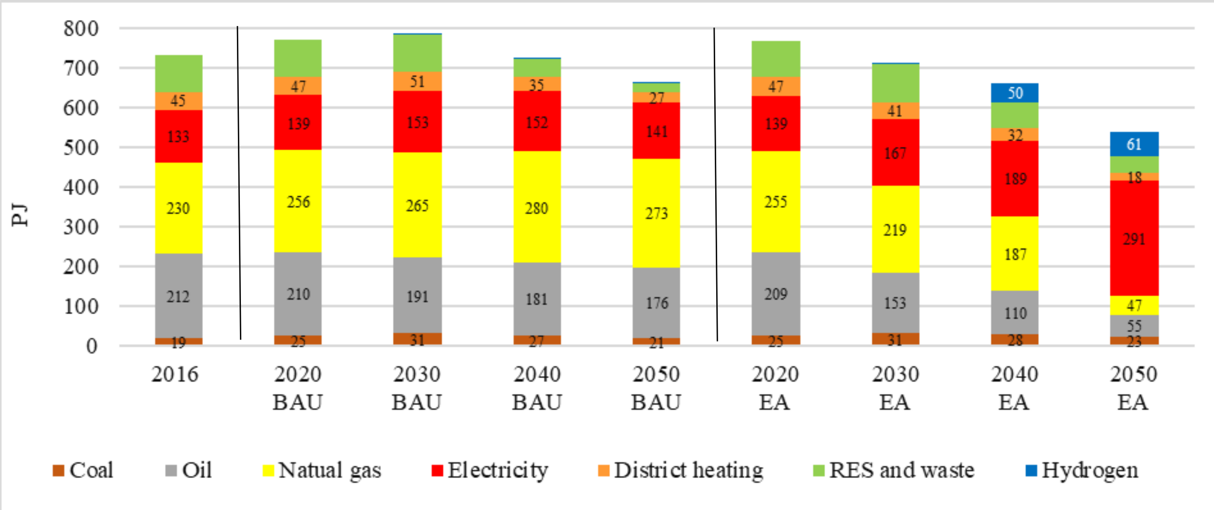
Fuel composition of final energy consumption – hydrogen partly replaces natural gas; high degree of electrification

The composition of final energy consumption needs to change significantly to reach the climate neutrality target by 2050 (Figure 21**).**

There is no significant shift in the BAU scenario, and even the share of natural gas is increasing, displacing mainly renewable energy sources. **The biggest change in the EA scenario is due to large-scale electrification, which affects the entire spectrum of the energy sector**. By 2050, electricity consumption will account for more than half of total energy consumption. The high degree of electrification is accompanied by a drastic increase in electricity production. As a result of electrification in transport, oil consumption will fall dramatically by 2050 to a quarter of the current use.

The other significant change, which will start in the 2040s, is the decline in natural gas consumption and the complete disappearance thereof in some sectors. Natural gas is partly replaced by hydrogen, mainly in the transport and industrial sectors. Hydrogen plays an important role, providing 10–15% of final energy consumption, partly through blending into the natural gas grid. The maximum blending rate in 2050 is 50%. This is a theoretical average value, which shows that half of the domestic "gas consumption" (theoretical mixture of hydrogen and natural gas) will consist of half natural gas and half hydrogen. There will be dedicated hydrogen pipelines that will supply 100% pure hydrogen as well as sectors and activities where pure hydrogen will be needed (e.g., transport, industrial raw materials). The 50% of hydrogen will not be fed into the natural gas network.

At first glance, it may seem surprising that the use of renewable energy sources in both scenarios will fall to a third/quarter of the current level by mid-century. This can be explained by the fact that the limited use of biomass is utilized in electricity generation, where the greatest GHG savings can be achieved with the help of biomass power plants equipped with CCUS technology.

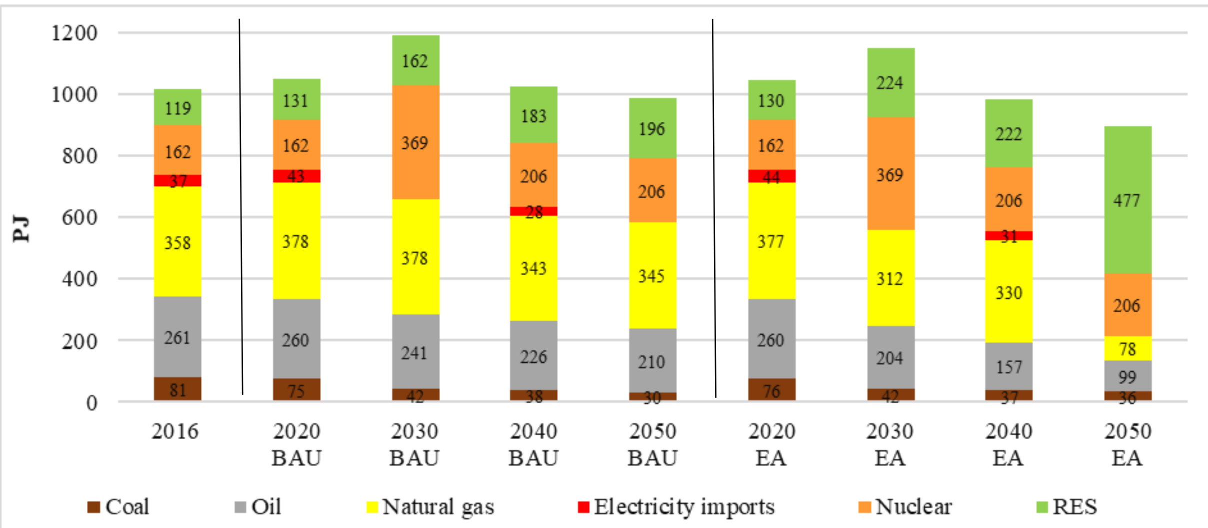


Source: Eurostat, own modeling result

Figure 21 – Final energy consumption fuel composition in each scenario, 2016–2050 (PJ)

Fuel composition of primary energy use—strong renewable penetration by 2050

There will be an increase in primary energy consumption until 2030, in both the BAU and the EA scenarios, since the new Paks nuclear power plant units will be commissioned, and even the old units will run in parallel during this period. However, even then, the two scenarios begin to separate; differences can be found in the use of natural gas and in the case of renewables. For the BAU scenario, the rate of primary energy consumption will be at the current level by 2050, while under the EA scenario it will fall below 900 PJ. In the latter scenario, **a strong renewable dominance in the primary energy mix can already be observed in 2050**, resulting from the high use of solar energy as well as biomass and biofuels (**Hiba! A hivatkozási forrás nem található.**).



Source: Eurostat, own modeling result

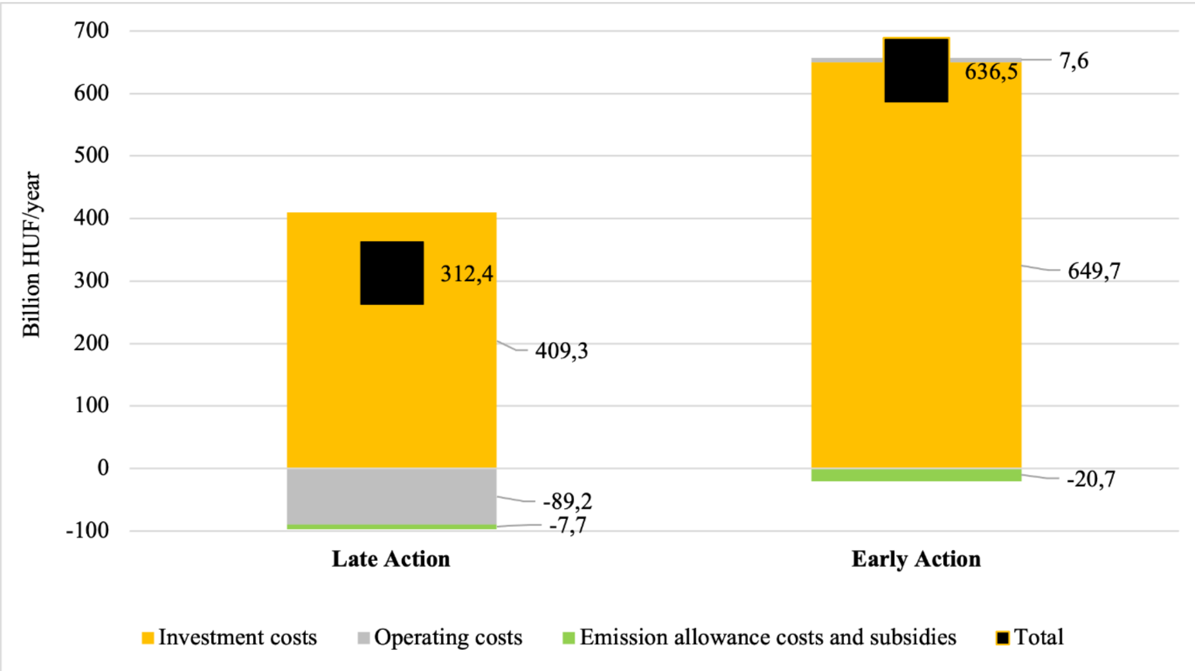
Figure 22 – Fuel composition of primary energy use in each scenario, 2016–2050 (PJ)

The social cost of the sectoral goals—HUF 637 billion per year is required

The HU-TIMES model provides an opportunity to quantify the additional costs of achieving the goals in the energy sector (Figure 23). These costs are not entirely borne by public finances; the way in which the burden is shared between the state and private actors depends on the regulation of the given subsector.

The analyses distinguish three main cost categories: investment cost (capital expenditures - CAPEX), operating cost (OPEX), and EU ETS quota costs and subsidies. The latter include the amount of support for renewables and the cost of CO_2 quotas for companies covered by the EU ETS. It is important to emphasize that the HU-TIMES model only quantifies the costs in the energy sector; the benefits—for example, avoiding the costs of air pollution or the impact on GDP—are simulated by the GEM model.

The largest change can be observed in investment costs. In the case of the EA scenario, there is an additional investment need of HUF 650 billion per year compared to the BAU scenario, which is offset by the lower operating costs and the lower amount of quota costs/subsidies. **The net value of benefits and costs represents an additional cost of HUF 637 billion annually to achieve the goals of the sector.**



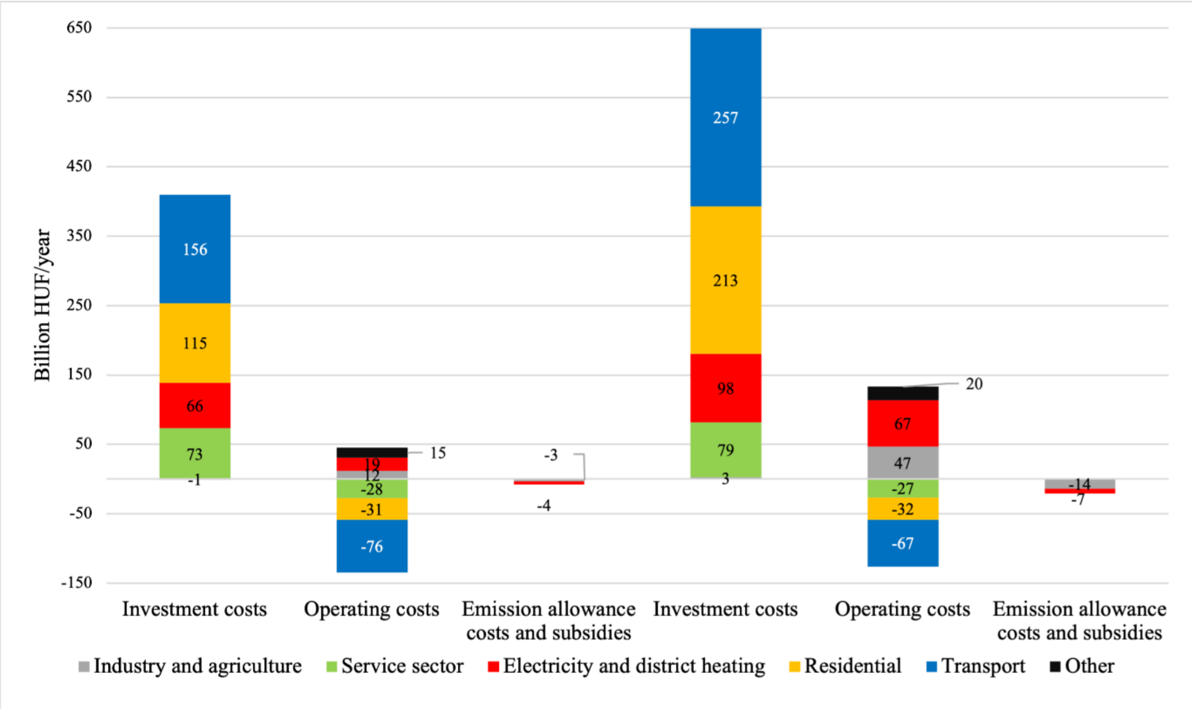
Source: HU-TIMES modeling result

Figure 23 – Distribution of annualized additional costs by category compared to the BAU scenario, HUF billion/year

Additional investment costs are mostly concentrated in the transport sector and households, respectively (Figure 24**).** In the EA scenario, the additional investment cost required in the transport sector is HUF 256 billion per year (40% of the total additional investment); in the residential sector, it is HUF 210 billion annually (33%). The electricity and district heating sectors account for 15% of investments, while the service sector accounts for 12%.

There is no significant additional investment cost for the industrial segment. This is because investments that are made in the EA scenario are also taking place in the BAU scenario. At the same time, in the case of the industrial sector, a change of fuel is indicated by the projections of the climate-neutral scenario, which can also be seen in the change of operating cost. In order to meet 2050 targets in the energy sector, it is necessary to switch to more expensive, cleaner fuels (e.g., carbon-free hydrogen or electricity).

As a result of additional investments, however, operating costs will decrease in the household segment, transport, and the service sector. This is due to factors such as an increasing number of vehicles with lower fuel consumption or energy efficiency investments (e.g., insulation, window replacement, more efficient heating).



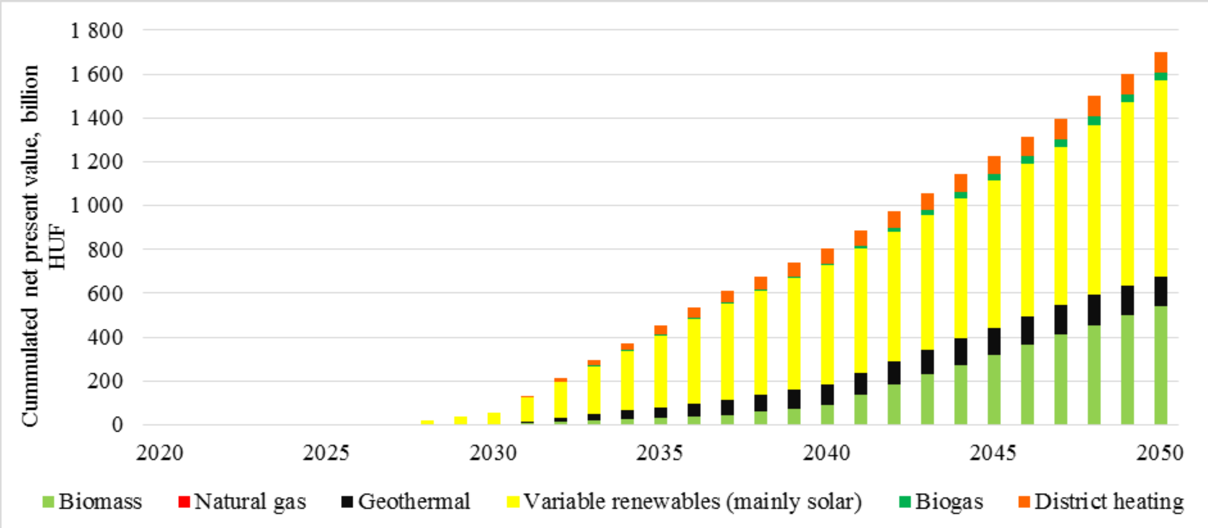
Source: HU-TIMES modeling result

Figure 24 – Distribution of annualized additional costs of LA and EA scenarios compared to the BAU scenario, HUF billion/year

In the cost analysis, the impact of allowance prices for the EA scenario **was analyzed using a sensitivity analysis, assuming that the price of CO_2 allowances would be doubled between 2030 and 2050. As a result, the cost of achieving the decarbonization target will increase by about 1.5%, by HUF 10 billion annually.** At the same time, higher quota prices have an incentive to achieve the targets by making pollution a more serious cost factor for companies.

The HU-TIMES model also provides an opportunity to show investment costs in more detail, especially in the transport, electricity, and district heating sectors.

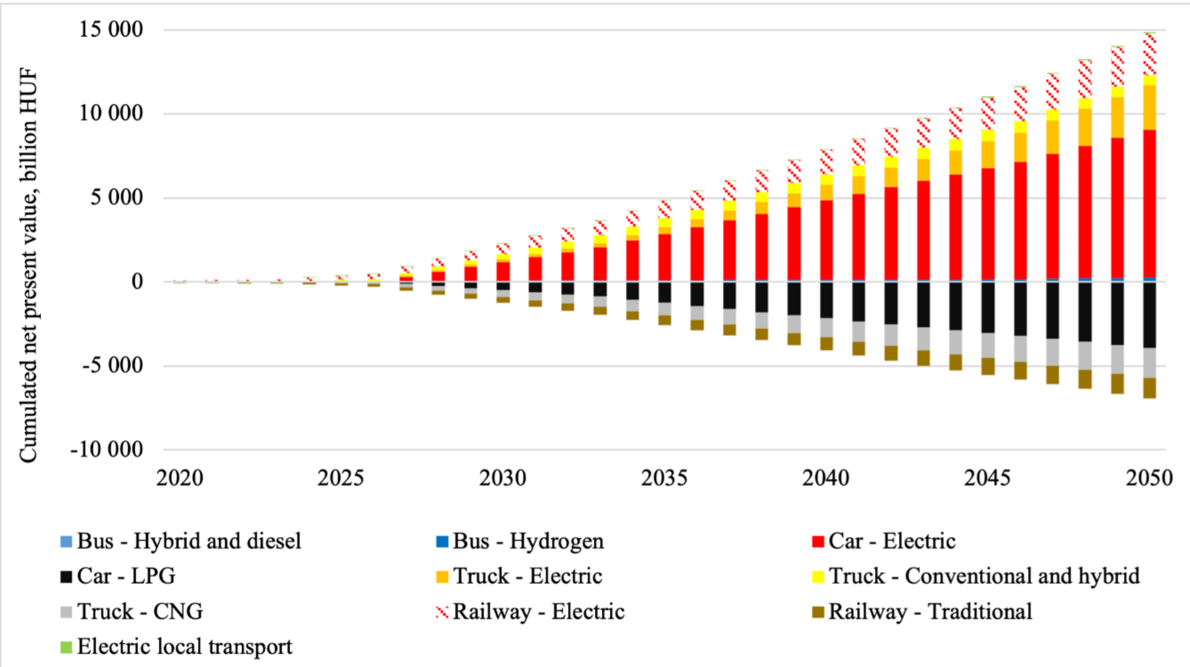
In the electricity and district heating sector, the differences in investment costs between the EA and BAU scenarios are shown in **Hiba! A hivatkozási forrás nem található.**. Costs show discounted, cumulative values for 2016. In total, by 2050, an additional investment of about HUF 3 600 billion is needed to achieve the net zero emission goals. The additional costs will be evenly distributed until 2045, after which additional investment costs will be higher.



Source: Eurostat, own modeling result, HU-TIMES modeling result

Figure 25 – Difference in the net present value of the annual cumulated investment costs of the EA and BAU scenarios in the electricity and district heating sector, HUF billion/year

The transport sector shows a significantly more heterogeneous picture (**Hiba! A hivatkozási forrás nem található.**).



Source: Eurostat, own modeling result, HU-TIMES modeling result

Figure 26 – Difference between the net present value of the annual cumulated investment costs of the EA and BAU scenarios in the transport sector, HUF billion/year

The total net additional cost amounts to HUF 10 000 billion; however, there are investments that are implemented only in the BAU scenario, while others appear only in the EA scenario.

In the latter case, the largest item (compared to the BAU scenario) is electric cars, but the additional investment costs of vehicles using railway electricity and trucks using electricity are also significant. However, in the case of the EA scenario, there are cost elements that are absent, as opposed to the BAU scenario. Less should be spent on LPG-powered cars, on compressed natural gas (CNG)-powered trucks and on diesel-powered railway cars in the EA scenario, compared to the BAU scenario. The incurrence of additional investment costs over the whole period is almost linear for the transport sector.

Decarbonization of households requires a reduction in natural gas and the spread of alternative solutions (especially heat pumps)

Household energy consumption (**Hiba! A hivatkozási forrás nem található.**) is also declining in the BAU scenario. This is mainly due to the low energy consumption of newly built buildings. In many cases, the renovation of buildings is a profitable investment; that is, the post-renovation utility savings can compensate for the renovation costs. In terms of fuel composition, firewood use will constantly decline from an initial level of 74 PJ to a few PJ by 2050. This is because households are switching to more efficient and, in the long run, more economical fuel, especially natural gas. In the case of natural gas consumption, a slight increase can thus be observed. Electricity consumption is declining due to the expected replacement of household appliances, as new appliances operate at significantly lower energy intensities.

The EA scenario already shows other trends in 2030. Due **to stronger energy efficiency investments, the energy consumption of this sector will be almost 50 PJ lower in 2030 than in the BAU scenario.** Energy efficiency investments will continue beyond the 2030s. At the same time, there is a constant shift in fuel: natural gas is decreasing and will be pushed back to a minimum level by 2050 according to the EA scenario. Meanwhile, coal is disappearing from the energy mix[14], contributing to making net zero GHG emissions available at the national level as well.[15] In this regard, a large-scale infrastructure development is imminent. For example, the solar panel program will be part of the transformation. There are also pilot projects targeting municipalities where natural gas is currently not introduced.[16] The experience gained during these projects will also be an important and key element of the transition.

As biomass (i.e., firewood) is only available to a limited extent, the use of this type of fuel is reduced to a minimum. In the EA scenario in 2040, hydrogen will appear as energy blended into the natural gas grid, but this is more of a temporary solution as electricity will remain the only widely available, zero emission fuel in the long run.

Consultations with stakeholders have also confirmed that one of the most cost-effective ways to achieve the long-term decarbonization target is to increase energy efficiency in the household and service sectors and to use renewable electricity, which requires the promotion of decentralized—prosumer—networks.

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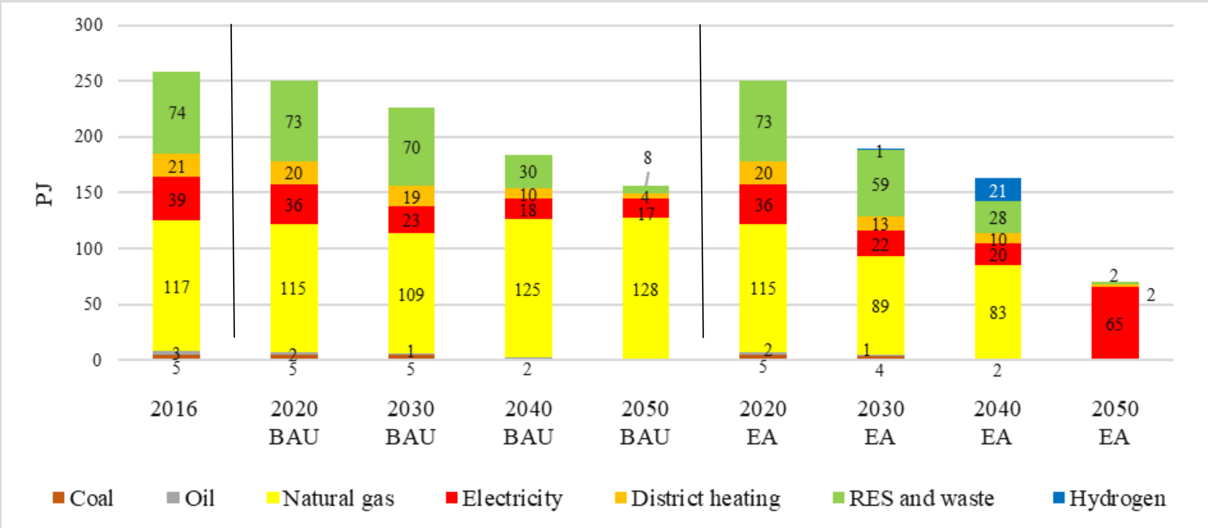
[14] The elimination of coal combustion is also important from the point of view of air pollution. Restrictions on the use of certain solid fuels by the population and making the social fuel support system more environmentally friendly are listed among the measures to be taken in the National Air Pollution Reduction Program.

[15] Further details on the measures planned in connection with the utilization of gas pipelines in Hungary can be found in Hungary's National Energy and Climate Plan adopted in January 2020.

[16] Within the framework of the energy innovation tender package announced in March 2020, the call "Ensuring the energy supply of settlements using alternative gas supply methods and using modern technologies and flexibility services" was announced, with a budget of HUF 3 billion.

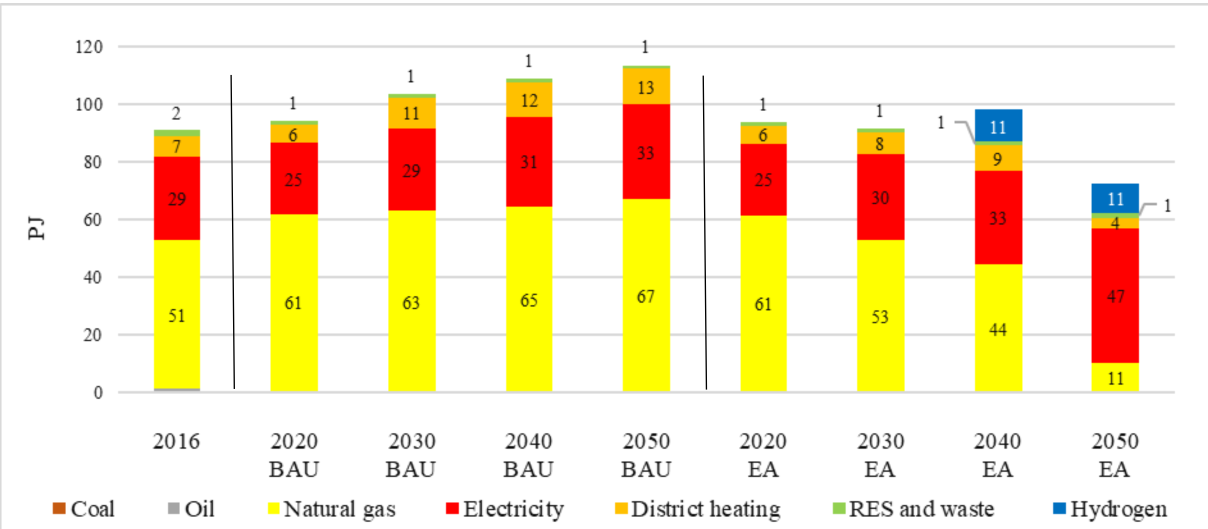


Source: Eurostat, own modeling result

Figure 27 – Distribution of energy consumption of the household sector in the BAU and EA scenarios

Electrification and partial natural gas phase-out in the service sector

In the case of the BAU scenario, the **energy consumption of the service sector** (**Hiba! A hivatkozási forrás nem található.**) will also increase from 91 PJ in 2016 to 113 PJ, which is generated by GDP growth and cannot be offset by energy efficiency investments. The fuel composition does not change significantly.



Source: Eurostat, own modeling

Figure 28 – Distribution of energy consumption in the service sector in the BAU and EA scenarios

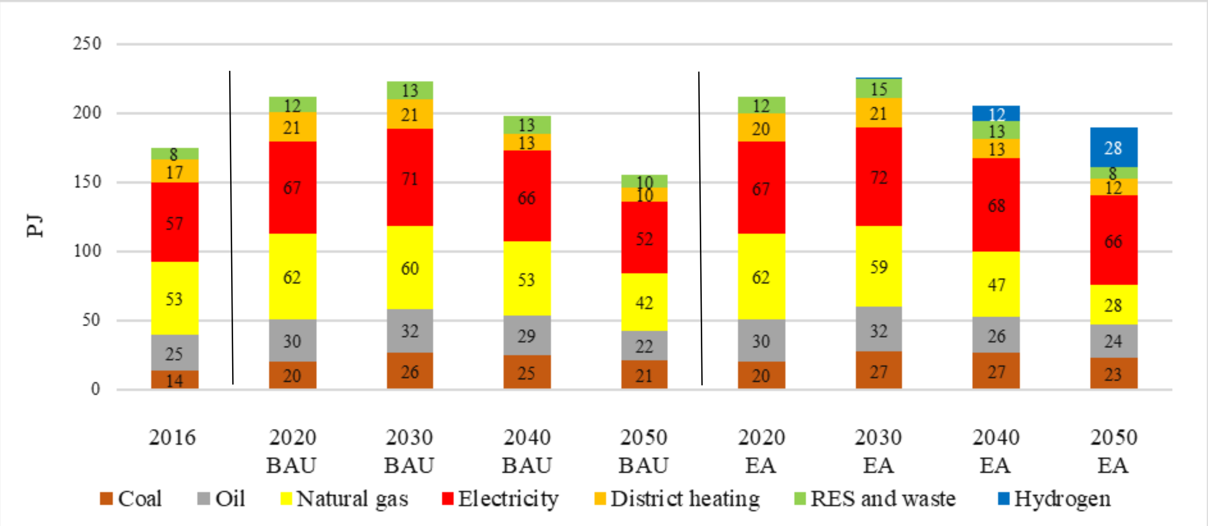
The implementation of the EA scenario presupposes important changes. While energy consumption will stagnate and increase slightly until 2040, a declining trend will emerge afterward. Although the energy savings are significantly lower than for households, it seems that intervention is needed to reduce energy consumption in the energy sector. Such a regulatory tool could be the energy efficiency obligation scheme to be introduced, investments, or operating subsidies, but these could include direct (e.g., prohibitive) instruments as well. There is also a significant change in fuel composition: the consumption of natural gas will decrease significantly, accompanied by an increasing proportion of hydrogen. Moreover, a high degree of electrification will be achieved by **2050,** when **electricity will account for two thirds of the energy consumption of the entire service sector.**

In addition to CCUS, hydrogen and electrification play a key role in the partial decarbonization of industry.

The change in industrial *energy consumption* (Hiba! A hivatkozási forrás nem található.)**) is characterized by an upward trend in the beginning in both the BAU and EA scenarios, but energy consumption will start to decline from the 2030s due to the energy efficiency investments.** In both scenarios, these investments are driven by the market, i.e., there is no need for government incentives. In the EA scenario, the rate of energy reduction is lower than in the BAU scenario. This is due to the fact that higher investments in the national economy increases GDP, which increases industrial demand, including energy consumption.

While there is no significant change in the fuel structure in the BAU scenario, a substantial realignment can be predicted in the EA scenario. Hydrogen will appear from 2040 and will play an increasingly important role, accounting for 15% of total energy consumption by 2050. Hydrogen primarily replaces natural gas. During the consultation stream called “Climate Breakfasts” held in 2020, the role of hydrogen was also highlighted by the private sector actors as an important factor in industrial decarbonization.

The stakeholder consultation also confirmed the importance of digitization and electrification in the long-term process of industrial decarbonization. In addition, representatives from the private sector stressed the need to increase energy efficiency. They consider it particularly important to introduce incentives for research and development to ensure the competitiveness of domestic actors in the development, production and export of new, energy-efficient and renewable energy-based technologies.



Source: Eurostat, own modeling

Figure 29 – Distribution of energy consumption in the industrial sector in the BAU and EA scenario

Electrification, biofuels, and hydrogen are all needed for the partial decarbonization of the transport sector

In the **transport sector** (**Hiba! A hivatkozási forrás nem található.**), energy use is increasing in both the BAU and EA scenarios, albeit to very different degrees. While energy consumption will increase by about 50 PJ in the BAU scenario between 2016 and 2050, this value will be only 8 PJ in the EA scenario.

Diesel consumption will decrease the most by 2050: to 34 PJ in the BAU scenario, while in the EA scenario, this fuel will completely disappear by the end of the period. This requires regulatory intervention that either supports the spread of cleaner solutions (e.g., subsidizing electric cars) or penalizes (e.g., higher tax), possibly limiting fossil fuel technologies.

Hungary is already taking significant steps to promote electromobility. **Electromobility and electric propulsion are expected to become increasingly important in the future**, so the market is expected to adapt more and more to new circumstances on its own and require fewer incentives. Already in the BAU scenario the electricity consumption in 2050 will be 37 PJ, which could thus account for 17% of the total transport sector without further action. In the EA scenario, this value is already close to 60% (111 PJ).

Electrification in road transport and its impact on the Hungarian automotive industry

Electric vehicles are becoming more and more widespread in Hungary as well. In terms of the spread of battery-powered electric cars (electromobility in the narrower sense), Hungary is already one of the leading players in the region, and in the long run, hydrogen-powered cell electric propulsion[17] will also have to be reckoned with. This process is also supported by the tightening of EU environmental standards for motor vehicles.

In the short and medium term, we must reckon with the expansion of battery electric propulsion and its effects on the automotive industry. In addition to the emergence of new technologies, electromobility poses a challenge to the domestic supplier network, partly because it reduces and, on the other hand, transforms the need for parts, given that electric cars are made up of fewer and different types of parts. The production of electric powertrains will also change the number of employees and the necessary qualifications: fewer and partly new competencies will be needed in the sector. As a result, a transformation is expected in Hungary's automotive supply and service chain and workforce.

How Hungary and the Hungarian automotive sector can and will remain competitive in this currently changing environment depends to a large extent on increasing Hungary's innovation capacity (including knowledge) and its willingness to restructure. “In Hungary, in recent years, investments in the automotive industry have been made in new and developing areas, such as the production of batteries and electric motors. The most likely scenario points to a reorganization within the industry, where the economic performance of the sector will not decline but its fundamentals will gradually change.” [18]

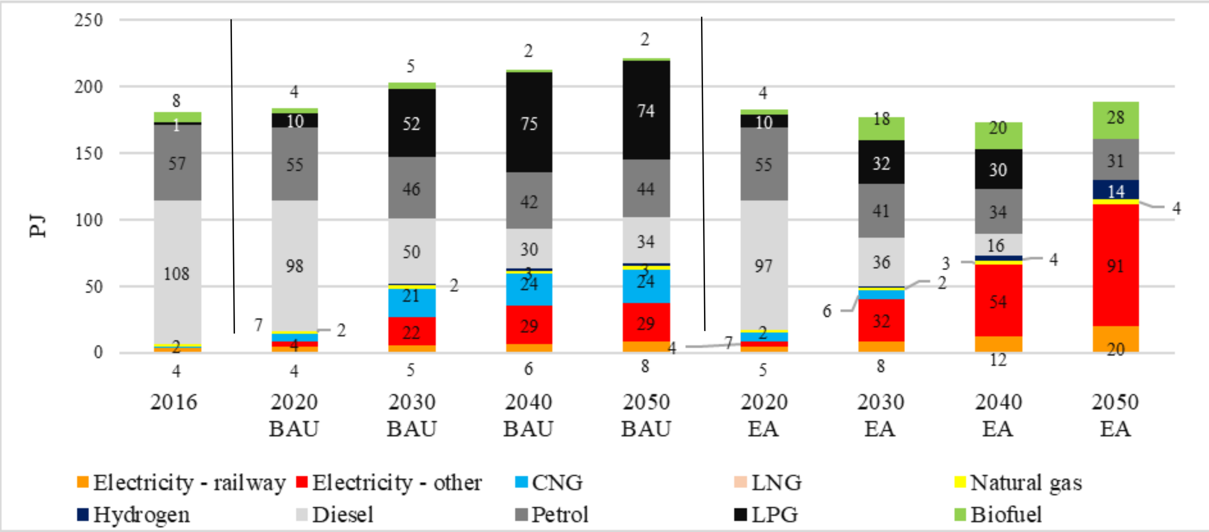
The use of hydrogen in transport is also essential to achieve the decarbonization goals. Hydrogen will appear to a greater extent in the 2040s, and by 2050 its share will be significant (8%). The biofuel share will be twice as much, with the rise of second-generation biofuels, and the relegation of first-generation biofuels to the background.

Consultations with industry representatives have also confirmed that decarbonization can be promoted in the automotive industry through fuel switching and the introduction of hydrogen, as well as a change of approach. In order to significantly reduce GHG emissions, it is

[17] By combining hydrogen and oxygen, a smaller battery is placed between the fuel cell that produces energy and the electric motor, ensuring that the right amount of energy is available to the engine in all cases.

[18] PWC (2018). Hungarian Automotive Supplier Survey 2018. Available at: https://www.pwc.com/hu/hu/kiadvanyok/assets/pdf/automotive_survey_2018.pdf

justified, in consultation with industry, to support the purchase of "clean" electric vehicles (battery-powered vehicles and hydrogen fuel cell buses) for public transport, as well as the appropriate development of the charging station network and infrastructure.



Source: Eurostat, own modeling

Figure 30 – Distribution of energy consumption in the transport sector in the BAU and EA scenarios

There are also significant changes in the transport modes (Figure 30**).** While in the BAU scenario, the energy consumption of passenger cars will decrease only slightly, in the EA scenario it will be reduced by about two-thirds by 2050. **Passenger transport is partly diverted to rail and bus**, which have a significantly more favorable GHG balance per passenger-kilometer. Cycling and car sharing should also be further promoted.

As far as *bus traffic* is concerned, a pilot project has been developed to replace the public transport bus fleet locally. The aim of the Green Bus Program[19] is to replace the local public bus fleet by encouraging domestic bus production, to reduce the average age of operated buses, the emission values and maintenance and operating costs of bus transport, and to improve the quality of travel services.

Regarding railways, the goal is that by 2040, all electric traction vehicles will be able to produce the most efficient traction known today, with significantly lower consumption during braking and fed back into the grid or own battery than most models running today. Non-electrified line sections can be accessed by battery-powered vehicles, the acquisition of which is planned to be phased in from 2021 onwards.

With the current level of *cycling*, a reduction of 15.25 million tons of CO2 emissions per year can be achieved in Europe. This reduction in emissions occurs precisely in the most problematic, densely populated urban areas, and therefore greatly improves the health, quality of life and livability of cities living there. In addition to traditional cycling and the

[19] Government resolution 1537/2019 (IX. 20.) on the tasks related to the new bus strategy concept of Hungary and the Green Bus Model Project.

necessary infrastructure, electric bicycles and scooters can play a greater role in urban transport and its decarbonization in the long term.

Other areas affected by GHG emissions from transport

The Paris Agreement does not cover **aviation**. Hungary discusses GHG emissions and environmental impacts from aviation under the auspices of the EU and ICAO, and the issue can only be regulated on the international stage efficiently.

Domestically, there are essentially only sport flights, small leisure flights, education and military flights, which are not as significant in terms of environmental impact as scheduled air traffic. Thus, the volume of domestic aviation in Hungary, as well as the resulting emissions are marginal, and their growth is not expected under current trends.

In terms of the environmental impact of aviation, the reduction in the volume of emissions is expected in the long run from technological developments (e.g., new types of aircraft, alternative fuels), not from a reduction in the number of aircraft movements.

On shorter travels, replacing aviation with other modes of transport may also be an option, e.g. high-speed rail, may result in emission reductions. This may require the development of multimodal transport and combined tickets.

A significant part of passenger and freight **water transport** is made on river the Danube; the domestic fleet accounts for about 15% of the international freight traffic affecting Hungary.

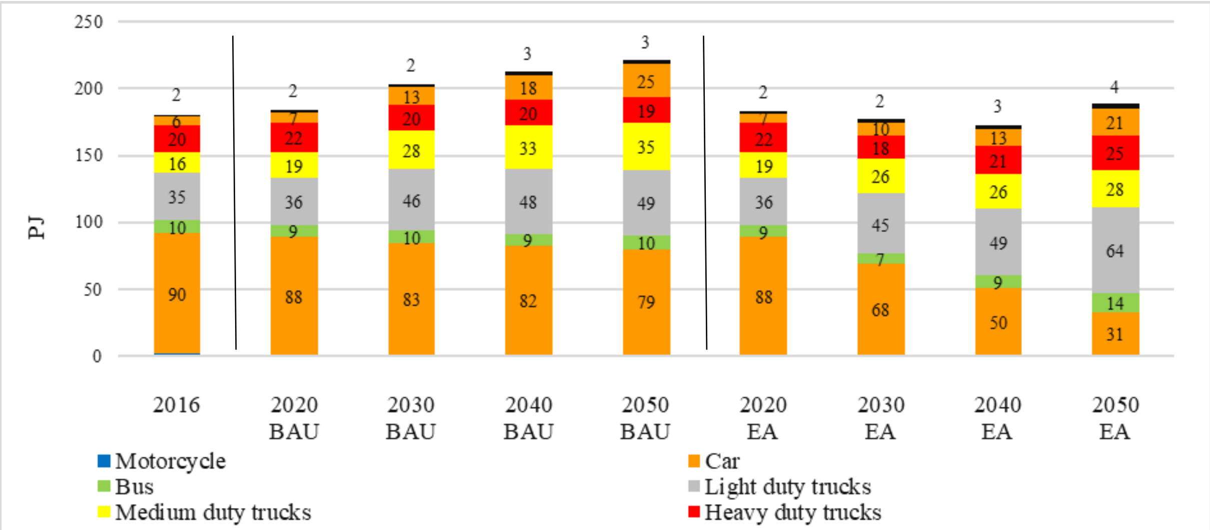
The Tisza River also has significant potential for inland freight transport, which can be considered environmentally friendly compared to road and air transport, but the successful diversion of goods requires the development of infrastructure.

In 2018, there were 14 pusher craft, 70 self-propelled cargo ships, 133 passenger ships and about 24,000 small craft in the Hungarian register (Central Statistical Office (KSH), 2018).

With regard to water freight and passenger transport, liquefied natural gas (LNG) and compressed natural gas (CNG) technology do not make a significant difference in terms of GHG emissions compared to diesel fuel.

Hydrogen has a potential in shipping as well, but the transition to it is still hindered by a number of factors (the life cycle of main engines and hulls is longer in shipping, technology change is a significant investment, there is currently no fuel supply network, etc.).

Electric boats have gained considerable ground in recreational boating in recent years, and one of the main drivers of development is the ban on the use of internal combustion engines on our great lakes; as a result, there are several competitive domestic companies in the market.

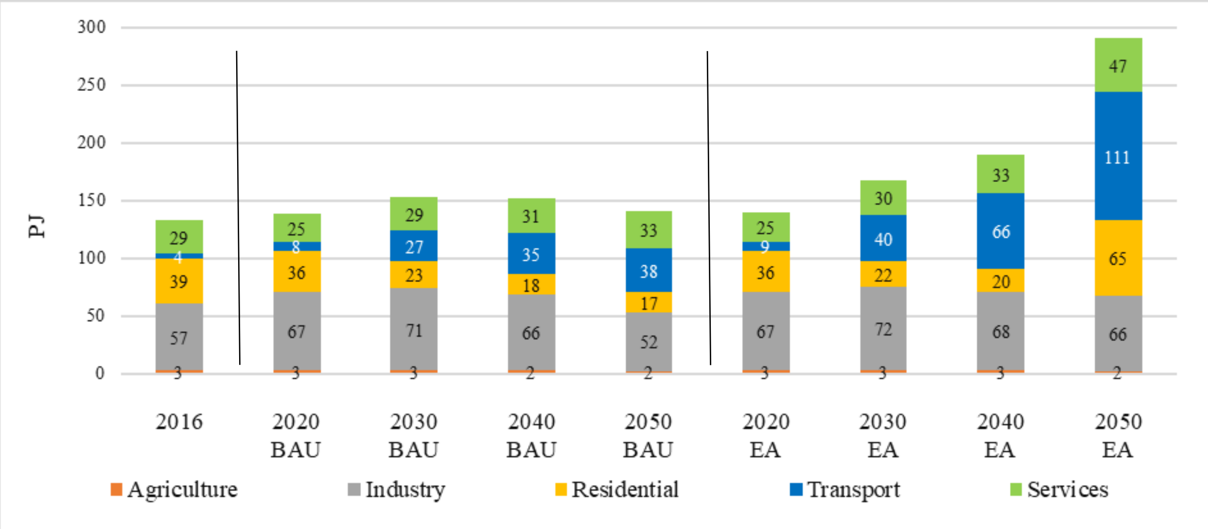


Source: Eurostat, own modeling

Figure 31 – Distribution of energy consumption in the transport sector according to different modes of transport in the BAU and EA scenario

Renewable and nuclear-based electricity consumption and generation

The energy sector as a whole is impacted by electrification, which is also the most important trend leading to decarbonization. In the case of the BAU scenario, electricity consumption does not really change: an increasing trend can be observed between 2016 and 2030, which then decreases, mainly due to industrial and residential energy efficiency investments. In contrast, a significant change can be seen in the EA scenario. From 2020 onward, strong growth is witnessed, driven decisively by the electrification of transport. However, the biggest increase will be in the 2040s, when consumption will increase from 190 PJ to 291 PJ, due to the electrification of transport and, with the spread of heat pumps, of the household sector. For the whole period, the growth rate is 2.2% (**Hiba! A hivatkozási forrás nem található.**).



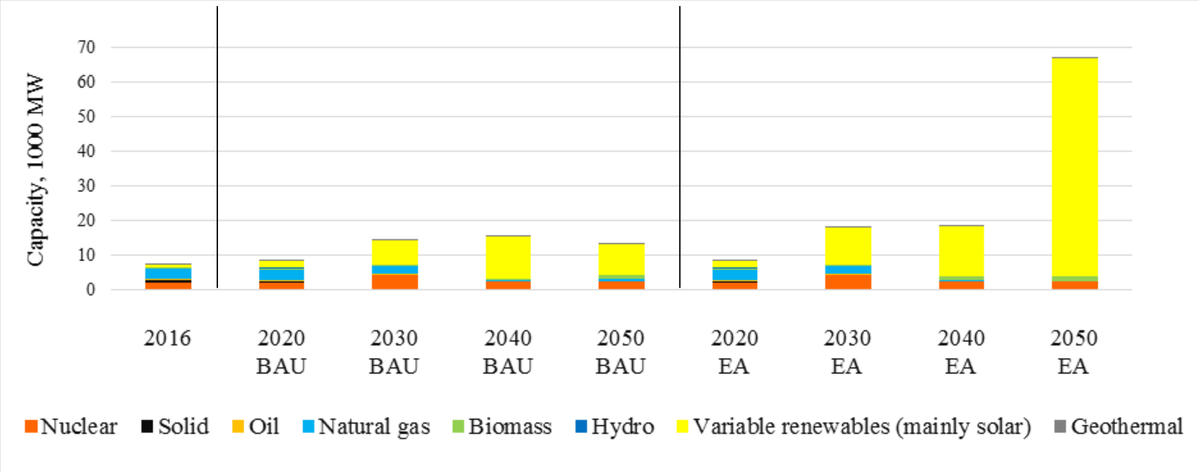
Source: Eurostat, own modeling

Figure 32 – Composition of electricity consumption in the BAU and EA scenarios

Such a significant increase in electricity consumption is accompanied by an increase in production demand. **Achieving the 2050 climate neutrality target and meeting consumption will require around 65 GW of clean generation capacity in addition to nuclear capacity**. Of this, 51 GW is photovoltaic energy (**Hiba! A hivatkozási forrás nem található.**).

The high degree of electrification accelerates in the 2040s. By then, support for the current modernization of residential heating systems will run out.

It is also important to note that, in accordance with the principle of sustainable land use, brownfield sites should be given priority in connection with the installation of renewable energy production capacities (especially solar panels).

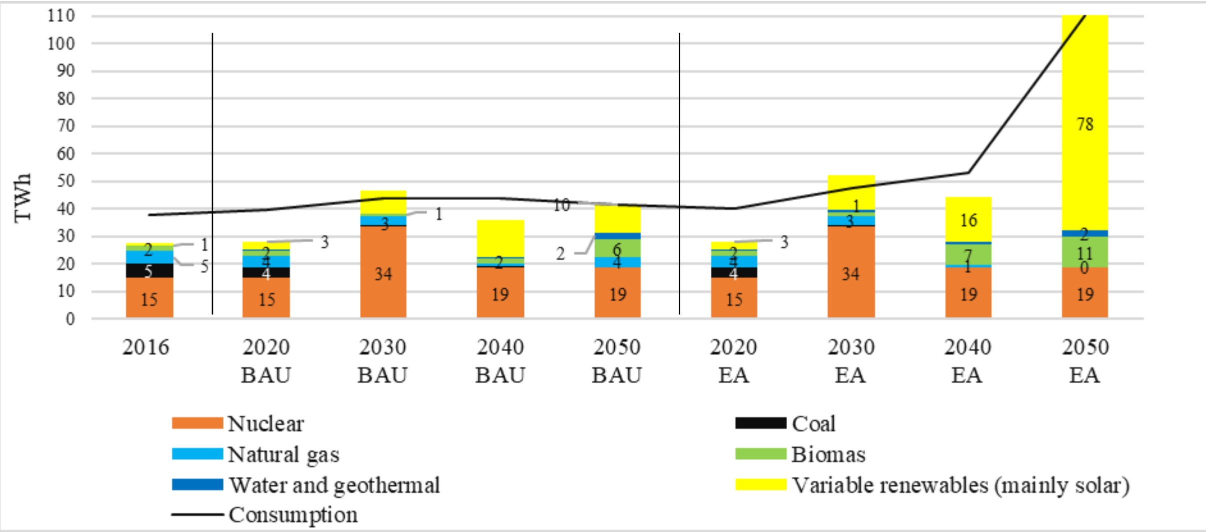


Source: Eurostat, own modeling

Figure 33 – Composition of installed electricity capacities in the BAU and EA scenarios

With the build-up of new renewable energy generation capacities, it will also be necessary to build storage capacity from 2040 onward for the system to have sufficient flexible capacity. Electricity storage capacities in 2050 in the EA scenario will amount to tens of gigawatts of capacity. The opinion of industry experts also confirms the important role of battery energy storage technologies, hydrogen, and the interconnection of the electricity and gas sectors through hydrogen in the decarbonization process.

In parallel with electrification, the security of energy supply will also be strengthened. In 2030, due to the parallel operation of the existing and new Paks units, Hungary will be a net exporter. Then, with the shutdown of the old nuclear power plant units, the country will become a net importer again. However, the import share in the EA scenario is only about half (16%) of today's levels. In 2050, due to the significant renewable energy production capacity and the available storage capacity, domestic production will almost completely cover consumption (**Hiba! A hivatkozási forrás nem található.**).



Source: own modeling results

Figure 34 – Composition of electricity generation in the BAU and EA scenarios

4.2.2. Industrial processes

Strengths Skilled workforce. Significant foreign and domestic investment in the industrial sector. Improved energy, process, and material efficiency. Economic policy focusing on building a green and efficient economy ("Hungarian, green and high-tech").	**Weaknesses** Unfavorable consumption habits (overconsumption, waste). Improving but still low climate awareness of the population Weaknesses in waste management. Limited integration of climate goals. Although the energy efficiency of the industry is improving, it still lags behind the level of Western Europe.
Opportunities Favorable base for RDI activity. Opportunities offered by hydrogen technologies. New economic development opportunities generated by green transition. Positioning and relocation of foreign chemical investors. Building a circular economy. Further digitalization and automation as well as the possibilities offered by artificial intelligence. Increasing consumer awareness. Strengthening cooperation between universities, research institutes and industry.	**Threats** Dependence on fossil fuels. Technological solutions that would help reduce process emissions in these sectors are typically not yet mature technologies. In some cases, there is a great deal of uncertainty about the technologies. Dependence on international supply chains and markets. Excessively high share of foreign capital in certain sub-sectors. Labor shortages in some areas. Passing on increased producer costs to consumers. New industries and technologies require new competencies that do not yet exist.

Table 5 – SWOT analysis of industrial subsectors with high process emissions

In modeling the decarbonization of industrial processes, the NCDS relied on a number of measures, good practices and technological solutions proposed by industry representatives. In addition to the use of renewable energy (mainly photovoltaics (PV)), the representatives of the companies drew attention to the need to increase the energy efficiency of production and to save energy and resources (circular economy). According to the proposals, new technologies such as CCUS, green[20] and blue[21] hydrogen can help to further reduce the carbon footprint of production processes that become more efficient through production optimization, digitization and the "Internet of Things".

In addition, the development and introduction of new technologies requires the support of companies' RDI activities, the training of professionals and the future retraining of workers in certain industries (e.g. car manufacturing), as technology change (electrification) and robotics will restructure the sector's employment.

Developments and main trends in past emissions

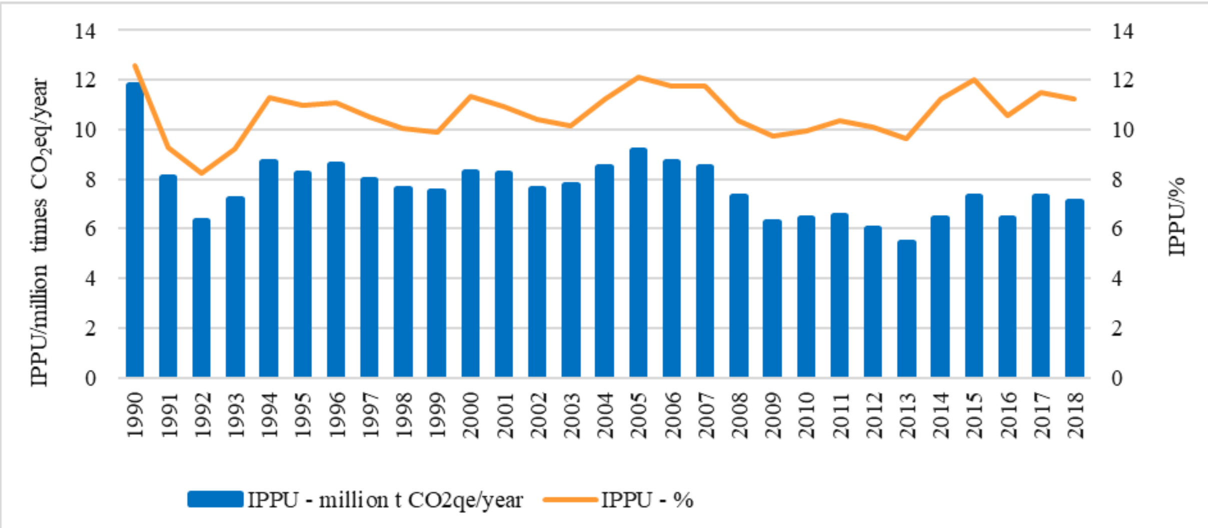
GHG emissions from industrial processes are derived from their energy consumption (see Section 4.2.1), and the industrial processes themselves also generate significant GHG emissions.

For most industrial activities, GHG emissions come only from the energy consumption required for production, but during certain industrial processes, such as cement production, ceramics production, chemical industry (e.g. petrochemicals, fertilizer production), large

[20] Hydrogen produced with renewable energy.
[21] Hydrogen produced from natural gas with SMR and CCUS technologies.

amounts of greenhouse gases may be released into the atmosphere. These gases account for a very significant share of the country's total anthropogenic emissions, about 10-12%.

Compared to 1990 and the middle of the 2000, emissions related to industrial processes and product use are developing favorably (Figure 35). At the beginning of the period, the decrease in GHG emissions was due to the decline in industrial production after the change of regime and the subsequent economic and industrial restructuring. However, as industrial production increased, output began to increase again, although the economic crisis of 2008-2009 resulted in another temporary decline. Emissions have risen again since 2010, but - despite dynamic economic growth - the sector's output is not even close to pre-crisis levels in 2008-2009. Economic growth is increasing the GHG emissions associated with industrial processes to a lesser extent in specific terms, as the sector has undergone significant material and process efficiencies, while also improving energy efficiency.



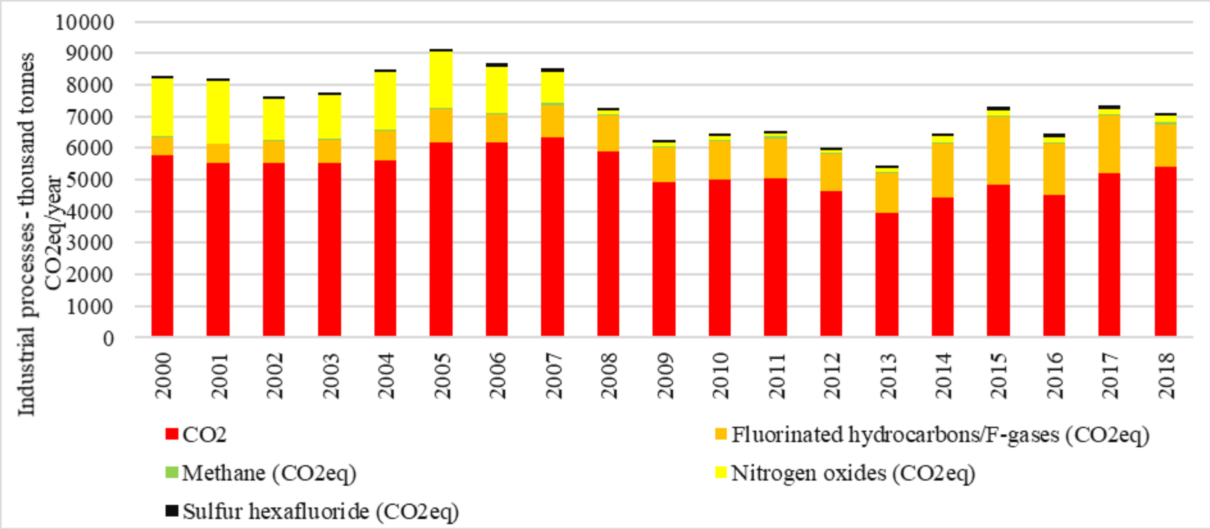
Source: EEA, Eurostat

Figure 35 – GHG emissions from industrial processes and product use (million CO_2eq/year), 2000-2018

The distribution of GHG emissions related to industrial processes and product use by gas type is illustrated in Figure 36. It can be clearly seen **that the ¾ of emissions is CO_2 emissions, but the share of fluorocarbons** (F-gases) **is also significant** (19% in 2018).

The vast majority of GHG emissions from industrial processes come from a few sub-sectors, and emissions are predominantly CO_2 emissions. In 2018, CO2 accounted for 79% of GHG emissions from industrial processes and product use, with methane and nitrogen oxides accounting for a further 12% and 8%, respectively.[22]

[22] The comparison was made according to CO_2eq / year.



Source: EEA, Eurostat

Figure 36 – GHG emissions from industrial processes and product use (million CO_2eq/year) by gas type, 2000-2018

Analyzing the development of emissions by subsectors (Table 6), it can be stated that the **chemical industry** clearly dominates, in 2018 the sector accounted for almost 37% of emissions related to industrial processes and product use. **Within this subsector, emissions are essentially related to petrochemicals** (petroleum refining), **ammonia production and nitric acid production**. Ammonia production is basically only responsible for CO_2 emissions, petrochemicals are mainly responsible for methane emissions, but the share of the sub-sector in CO_2 emissions has also increased (CO_2 emissions in the sub-sector have increased about 2.8 times compared to 1990). Emissions of nitrogen oxides are clearly caused by nitric acid production. For F-gases, 93% of emissions are from substances used to replace ozone depleting substances.

In addition to the chemical industry, the **metal industry** (20%) **and the production of mineral products** (19%) also play a significant role. In the case of the former, almost all emissions are related to iron and steel production, but some emissions are also characteristic of aluminum production. With regard to the production of minerals, cement production is a major emitting subsector. Emissions from the metal industry also include CO_2 emissions and methane emissions, while cement production essentially produces only CO_2 emissions.

	Total GHG emission (CO_2eq)	CO_2	Methane (CO_2eq)	Nitrogen-oxides (CO_2eq)	F-gases (CO_2eq)
Total industrial processes and product use	**100**	**100**	**100**	**100**	**100**
Mineral industry	**19**	**25**	**0**	**0**	**0**
Cement production	12	16	0	0	0
Chemical industry	**37**	**47**	**90**	**18**	**0**
Ammonia production	16	21	0	0	0
Nitric acid production	1	0	0	18	0
Petrochemicals	20	26	90	0	0
Metal industry	**20**	**26**	**10**	**0**	**0**
Iron and steel production	20	26	10	0	0
Aluminium production	0	0	0	0	0
Non-energy products originated from energy carriers and solvents	**1**	**2**	**0**	**0**	**0**
Production of electronic products	**0**	**0**	**0**	**0**	**0**
Product use to replace substances responsible for ozone depletion	**19**	**0**	**0**	**0**	**93**[23]
Production and use of other products	**4**	**0**	**0**	**82**	**7**

Source: EEA, Eurostat

Table 6 – Distribution of GHG emissions from industrial processes and product use between subsectors, 1990-2018 (CO2eq/year comparison)

F-gases

Substances that replace ozone-depleting substances, the so-called F-gases are powerful greenhouse gases that damage the climate a hundred times or even a thousand times more than carbon dioxide. They are widely used, for example in refrigeration equipment, air conditioners, fire-retardant foams, heat pumps, etc. Therefore, more and more stringent standards, labeling and regulations apply to the repair, maintenance and destruction of these devices. However, demand for air conditioning and refrigeration is projected to grow at a tremendous rate in the coming decades. It is therefore important that climate-damaging substances, like ozone-depleting substances, are phased out. In Hungary, the regulation of F-gases is determined by the legal acts of the EU: the F-Gas Regulation (Regulation (EU) No. 517/2014) and the so-called MAC Directive (Directive 2006/40 / EC). The main provisions of the F-Gas Regulation are:

- Limit the total amount of key F-gases that can be sold in the EU and gradually reduce it to one-fifth of 2014 levels by 2030.
- The use of F-gases is prohibited for appliances where a less harmful alternative is available (e.g. refrigerators or air conditioners in households or shopping malls)
- Prevent the release of F-gases from existing equipment into the atmosphere by introducing regular inspections, proper servicing, and rules for proper discharge at the end of their life cycle.

With the help of the F-Gas Regulation, F-gas emissions will be reduced by two thirds by 2030 compared to the 2014 value. In Hungary, approx. 2% of total GHG emissions are F-gases, which is below emissions from the industrial sector. According to the latest GHG inventory data, emissions from these gases decreased by about 25% from 2017 to 2018, reaching its highest level in 2015, but by 2018 it had fallen to a historic low. The main reason for this is the change in the quantity of used and sold equipment. Refrigeration and air conditioning equipment is undergoing significant changes, the main reason for which is the strict regulation introduced by the EU F-Gas Regulation. Hungary plans to further reduce F-gas emissions on the basis of the

[23] In essence, this covers emissions from the use of substances as a replacement of substances that deplete the ozone layer.

legislative framework of the EU.

Steps to be taken in the field of industrial processes to achieve net zero GHG emissions at the national level

In order to meet the net zero GHG emissions of 2050 at the national level, emissions related to industrial processes must be reduced to at least 200-250 thousand tons of CO_2eq/year by 2050.

Achieving the decarbonization goal in industry cannot be based on curbing production, instead efficiency investments and technological developments are needed. In order to effectively reduce process emissions, dramatic changes are needed in the future in those industrial sub-sectors that account for a significant share of GHG emissions, namely petrochemicals, iron and steel, ammonia and cement.

Emissions of nitrogen oxides (mainly N_2O) from industrial processes can be reduced relatively quickly as early as 2030, although further reductions thereafter are limited. It will be possible to accelerate the reduction of CO_2 emissions in the longer term.

In the industrial sector, in addition to the development of production/manufacturing processes and the increase of material efficiency, the use of CCUS technologies and alternative raw materials for the replacement of fossil-based energy sources used as certain raw materials may also be necessary in the future. Moreover, changing consumption patterns, and even more so the transition to a circular economy, will have a significant positive impact on reducing industrial emissions. The need to realize all of this is particularly shown by the fact that industrial production (chemical industry) and construction (and thus the demand for cement and iron and steel) will continue to expand, so without further interventions, emissions would increase two to three times by the middle of the century.

Innovative technologies for decarbonization of industrial processes: hydrogen and CCUS

In the future, carbon-free hydrogen and its derivatives, as well as CCUS technologies, may also play a key role in reducing emissions from industrial processes that are difficult to decarbonize.

With regard to hydrogen use, iron and steel production could be one of the potential area of applications. Iron is produced by a fire metallurgical process from iron ores, in which oxygen is removed from the iron ore by reduction with coke. This causes significant carbon emissions. However, reduction with carbon-free or low-carbon hydrogen may offer an alternative to decarbonized production. Hydrogen and its derivatives can also be used as a basis for decarbonizing chemical processes and petroleum refining. The production of fuels and chemical products is largely fossil-based, primarily hydrocarbon-based. Fossil hydrocarbons used as feedstock could be replaced in the future with synthetic hydrocarbons, which could be produced from CO_2 and carbon-free hydrogen removed from the atmosphere or other processes. Carbon-free hydrogen can also be considered for the production of ammonia, so that the use of ammonia and the use of other ammonia-based chemical products can also be made carbon-free.

Due to its high energy density, hydrogen can also be a viable solution for extremely heat-intensive industrial processes such as steam cracking (chemical/refining), iron and steel production (where coke also provides process heat) and clinker production (cement industry). In the cement industry, another process, the so-called calcination also involves significant CO_2 emissions, which occur when limestone (which consists of 90% calcium carbonate ($CaCO_3$)) is heated and decomposes to calcium oxide (CaO) and CO_2. In practice, this emission could be reduced by CCUS technology. (CCUS can, of course, also offer a solution for reducing emissions from thermal energy-intensive processes.)

In accordance with the above, the following factors need to be taken into account:

- Economic development and climate protection should be coordinated.

- In addition to identifying industries with high process emissions, it is strongly recommended to identify those **industries related to sustainability** that have the potential to help strengthen the country's long-term competitiveness.
- Reducing GHG emissions in industry to a minimum, close to zero, requires further modernization of **production and process efficiency** in certain sub-sectors. Digitization and automation are spreading further in the industry. In some cases, there may be a complete change in production technology in some areas, all on a market basis.
- There is additional potential for **material efficiency**. The GHG reduction potential in this respect can be identified mainly in the construction industry and in the chemical industry.
- **CCUS** technology will not only play a role in energy production, but also in making industrial processes more climate-friendly. Unfortunately, this technology does not yet offer a cost-effective alternative. (Further details on the technology can be found in Section 6.1.1.)
- The replacement of fossil fuels (as raw materials) with alternative, "clean" raw materials will take place in the medium to long term. Hydrogen and its derivatives (e.g. synthetic methane, synthetic ammonia) as well as biomass-based fuels may offer an alternative to carbon-free materials in the future. (For more details on the technologies, see Sections 4.2.1 and 6.1.1, respectively.)
- By reducing the amount of primary raw material consumption, significant emission reductions can be realized, which can be achieved primarily by implementing a **circular economy**. Building a circular economy is inconceivable without an industrial symbiosis approach based on the ability of the waste generated by one industry to be used as a raw material by other industries; and the importance of promoting waste prevention, recycling and other treatment efforts, and the collection and energy recovery of landfill gas from landfills and wastewater treatment plants. With the spread of recycling, the production of many industrial products such as steel, glass and plastics becomes more resource efficient. Banning single-use plastics generates additional positive effects. (See also section 4.2.5 on waste management.)
- The demand for raw materials and thus process emissions can be further reduced through effective attitude formation by **changing consumption patterns**. In this context, it should be noted that in the future, it would be important to make data on the carbon footprint of products and services available and transparent, so that conscious consumers can make informed choices.
- A significant part of the technologies with the greatest potential for emission reductions are not yet considered mature enough. Moreover, many solutions are still in the early stages of development. Therefore, further **Research, development and innovation (RDI)** activities are needed to move forward. In this context, consideration should be given to redesigning the RDI incentive and tendering system to take greater account of the need to improve the resource efficiency of industrial processes for climate purposes.
- It should be recognized and awareness should be raised that companies will only be able to meet the tightening standards and societal expectations and new competitive conditions created by the decarbonization transition if they themselves play an **active and responsible** role in the transition, they develop and innovate. The role of the state is to facilitate this– primarily, but not exclusively - by creating the right incentives and predictable framework conditions. (For information on innovation opportunities, see Chapter 6. For possible sources of funding for innovation, see Chapters 5 and 6.)

- Last but not least, there is a need to fully integrate climate change as a precondition into industrial development policies.

Emissions from energy use by industry are described in subsection 4.2.1.

Expected trends of the EU emission trading system (EU ETS)

The EU ETS is a key tool among EU policies to combat climate change to reduce greenhouse gas emissions in a cost-effective way. It is the world's first and largest carbon trading market. The EU ETS operates in all EU Member States, as well as in Iceland, Liechtenstein and Norway. It covers more than 11,000 installations (power plants and industrial plants) and controls about 40% of greenhouse gas emissions for all countries covered.[24]

The future of the EU ETS depends to a large extent on market integrity and a shared level of ambition, but the following trends are expected to shape the period ahead:[25]

Proposal for an EU climate law and raising the EU's 2030 level of ambition: If the EU commits itself to a higher level of ambition, the ETS is expected to be strengthened within existing scope of installations. Strengthening and fine-tuning the EU ETS and then extending its scope to other sectors not currently covered could lead to consistency in carbon pricing. The revision of the EU ETS due to the higher EU climate target for 2030 means a revision of the carbon cap by increasing the linear reduction factor (LRF).

EU ETS and energy system integration: a strengthened EU ETS has a key role to play in gradually facilitating energy system integration and encouraging uptake of least cost emission reduction technologies and solutions.

2021 review of the market stability reserve (MSR): The planned review of the functioning of the MSR in 2021, which will ensure that the market balance is maintained, will be accompanied by a review of the EU ETS as a whole.

Use of auctioning revenues: Under the EU ETS Directive, Member States are required to devote at least half of the revenues from the sale of EU ETS general-purpose allowances and all of the resources from the sale of aviation allowances to climate and energy investments. In addition, during the revision of the EU ETS Directive adopted in 2018, the Modernization Fund was established to support energy and energy efficiency investments in 10 low-income Member States (such as Hungary). These countries continued to receive a support mechanism under Article 10c of the EU ETS Directive to modernize their energy systems. It is also important to mention the Innovation Fund, which supports the first large-scale demonstration projects of some innovative technologies.

The EU ETS and the global carbon market: In the long run, the EU-ETS is expected to be linked to the carbon markets of other countries and regions in order to prevent carbon leakage and cost-effectively reduce global CO_2 emissions (where available). As a first step, in 2020, the interconnection with the Swiss ETS system became operational.

Decarbonization pathways of industrial processes

Under the BAU scenario, due to increasing production and without additional measures GHG emissions will double by 2050, exceeding 14 million tons of CO_2eq/year. **According to the EA scenario, industrial processes will become slightly less carbon free in the medium term than the economy as a whole, but a significant further reduction can be achieved by 2050**. Emissions reduction, material, process and energy efficiency measures and technologies (including, inter alia, digitization and automation, alternative "clean" raw materials) and even more so the transition to a circular economy will significantly reduce emissions to about 215 thousand tons of CO_2eq/year levels (Figure 37)

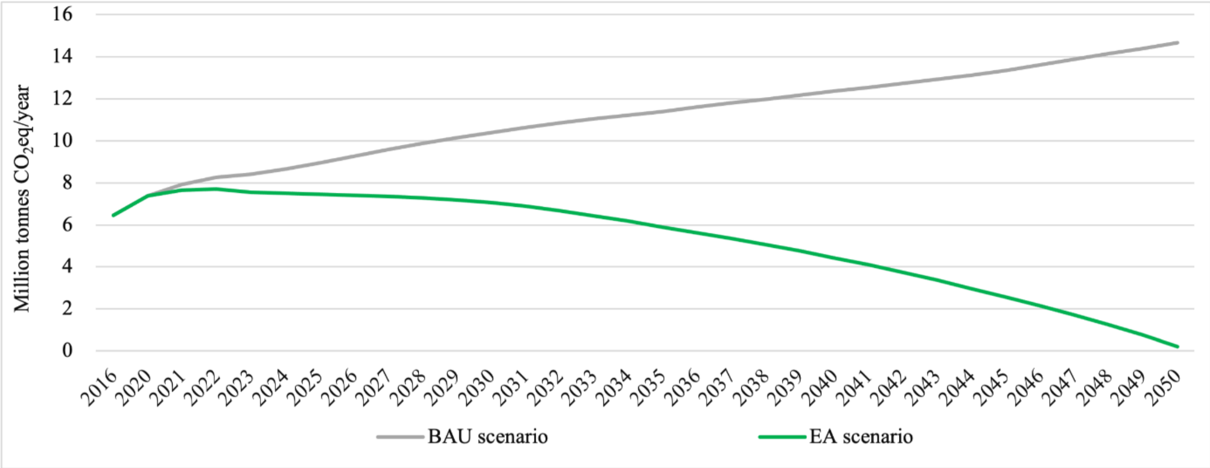
[24] For more information, visit https://ec.europa.eu/clima/policies/ets_en

[25] EFET (19 June, 2020), Future role of the EU ETS in achieving Europe's decarbonization targets; Available at: https://efet.org/Files/Documents/Emissions%20and%20RES/Emissions%20trading/2020/EFET_discussion%20paper_future%20role%20of%20the%20EU%20ETS_final.pdf

The domestic circular economy

An important national economic and environmental goal is the so-called shift towards a "circular economy", i.e., the production and use of zero waste, the more efficient, economical and at the same time more sustainable use of natural resources, the utilization of waste as much as possible, taking into account the priority of the waste hierarchy. The ultimate goal is to create a circular economic system where metabolic processes flow in a closed system, with high levels of waste and by-products being utilized in their material.

In order to start and gain the transition from the linear economy to the circular economy, the Circular Economy Platform was established in 2018. Within the platform, the professional work has already started, and a Working Group on the Circular Economy has been formed to support it. In the field of research and development, Bay Zoltán Applied Research Public Benefit Nonprofit Ltd. has been involved in this work (circular economy, cascade-like utilization of resources, waste hierarchy, extended producer responsibility, industrial symbiosis and new business models) by looking at the practical challenges of the transition to a circular economy through their applied industrial RDI activities.



Source: Eurostat, own modeling results

Figure 37 – Expected change of GHG emissions from industrial processes and product use between 2020 and 2050 under different

4.2.3. Agriculture

Strengths Agricultural restructuring based on innovation. More predictable revenues through the EU's common agricultural policy and domestic subsidies. Modernization of agriculture and consequent reduction of environmental impact.	**Weaknesses** Significant investment costs. Significant need for technology and human resource development. Significant need for political and other decision-making commitment.
Opportunities Sustainable intensification of agricultural production, taking into account the conservation of biodiversity. Near-zero GHG/pollutant, circular and waste-free farming. Digitization.	**Threats** Competition of cheaper agricultural products. Competition from Member States with more agricultural subsidies. Maintenance of the Russian embargo Lagging and failing measures. Unsustainable consumer habits and food waste.

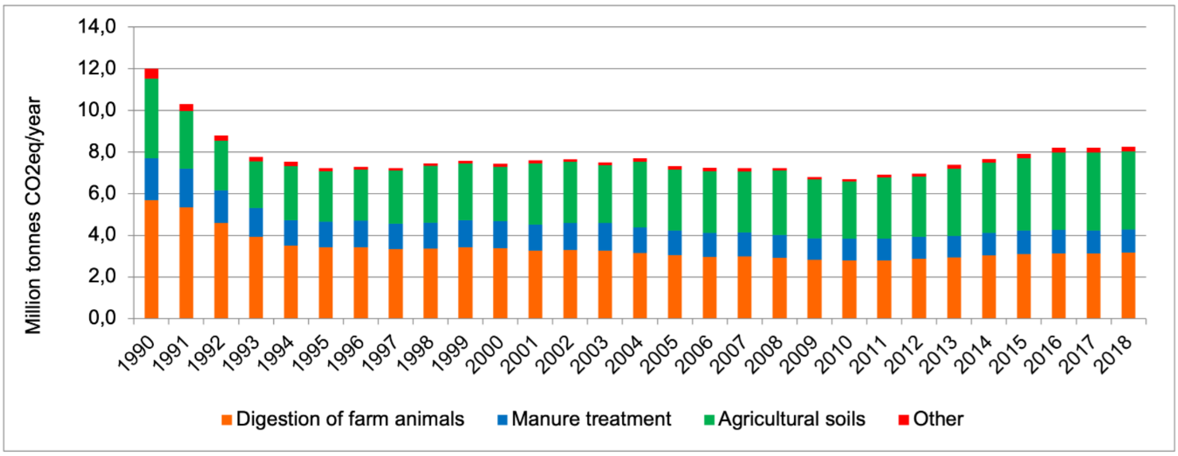
Table 7 – SWOT analysis of the agricultural sector

Developments and main trends in past emissions

In 2018, agriculture contributed 11% to Hungary's total GHG emissions. Agricultural activities emit methane and nitrous oxide, and most of country's nitrous oxide emissions (87%) come from this sector. **The main sources of GHG emissions in the agricultural sector are nitrous oxide emissions from arable land, emissions from manure treatment (nitrous oxide and methane) and digestion of farm animals (methane).**

Emissions fell sharply between 1985 and 1995, when agricultural production fell by more than 30% and livestock declined significantly. Between 1996 and 2008, agricultural emissions stagnated at around 6.2 million tons with fluctuations of ± 5%. In the background, the opposite effect emerged: a further decline in livestock would have led to lower emissions, but a significant, 68% increase in fertilizer use between 1995 and 2007 led to increasing N_2O emissions from soils. In 2008, fertilizer prices rose sharply, leading to a reduction in consumption and, as a result, emissions from agriculture.

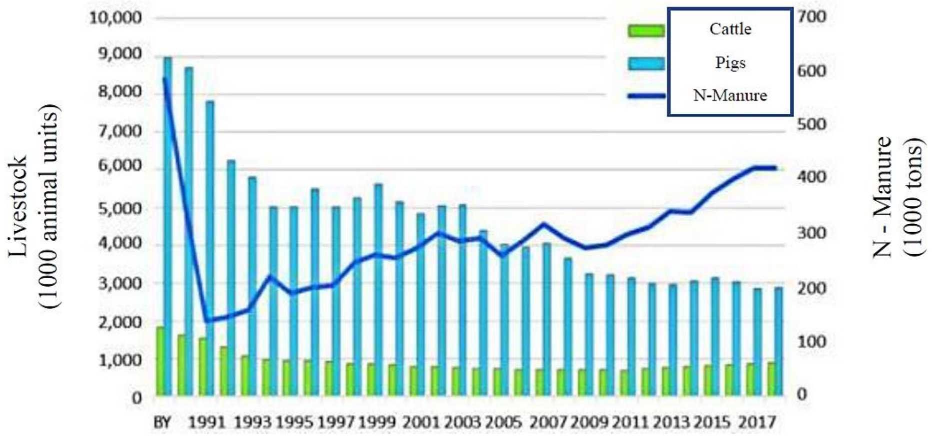
Agricultural emissions decreased both in 2009 and 2010 (Figure 38Figure 37). A more significant decline occurred in 2009, when, in addition to lower fertilizer use, an 11% decrease in the number of pigs also contributed to the reduction in emissions. Following emissions in 2010, the lowest since the base year, GHG emissions from agriculture have been steadily increasing since 2011, mainly due to higher number of cattle, the increased use of fertilizers, as well as milk production per cow. This growing trend continued in 2018. In 2018, GHG emissions from agriculture increased by 1.4% compared to 2017 and by 17% compared to 2005.



Source: National Inventory Report, 1985-2018.

Figure 38 – Trend of agricultural GHG emissions by inventory category between 1990 and 2018

The structural change that has taken place in agriculture since 2004, and the fact that crop production has become dominant in relation to animal husbandry, can also be traced in GHG emissions. Since 2004, the share of methane emissions, mainly from livestock, has been declining and nitrous oxide, mainly from crop production, has been increasing. Some types of fertilizers, such as urea-containing fertilizers and the lime-ammonium nitrate type fertilizers contribute to GHG emissions not only due to their nitrogen but also their carbon content. In particular, due to the growing popularity of the latter fertilizer in recent years, the associated N_2O and CO_2 emissions have tripled since 2005 (Figure 39).



Source: National Inventory Report, 1985-2018.

Figure 39 – Quantitative change in the dominant sources of agricultural GHG emissions between 1990 and 2018

Since 2010, where the level of emissions was the lowest since the base year, GHG emissions from agriculture have been steadily increasing, mainly due to higher number of cattle, the increased use of fertilizers, as well as milk production per cow.

Development policy goals for low GHG agriculture

The "Climate Breakfast" consultations with representatives of civil society organizations and the industries drew attention to the need to place particular emphasis on the conservation of biodiversity and the promotion of organic farming in sustainable agricultural practices. In addition, the use of irrigation can lead to increased emissions. Irrigation will produce higher yields than farming without irrigation. Along with agricultural production, the green mass is also increasing, more soil life is to be expected, higher nutrient consumption and even more pesticide use are to be expected. Therefore, all these factors will increase GHG emissions, which must be taken into account.

The most important tools for implementing low-carbon agriculture are:

Transition to precision farming, extensive use of Agriculture 4.0 and 5.0 toolkit.

● *Precision farming and Agriculture 4.0* toolkit, i.e., solutions for remote sensing of water, nutrient, pathogen and environmental stress status of cultivated crops and the possibility of precision interventions. The goal of precision farming is to reduce the use of pesticides, fertilizers and water, to improve soil productivity while optimizing crop yields. With soil scanning, soil mapping and nutrient application planning, only the required amount of nutrients is actually applied. Logistics, energy and fuel consumption are optimized. In animal husbandry more sustainable farming is based on targeted interventions based on continuous animal health, nutrient supply and performance monitoring.

● Nearly zero GHG/pollutant emissions based on *agriculture 5.0* toolkit (robotics, drone-based remote sensing, automation, industrial protein, carbohydrate and bioactive substance production, molecular farming, functional fertilizers and functional food and feed production bioherbicides, biopesticides) material-free, waste-free management.

Within the framework of the EU's common agricultural policy, the following measures are also expected to affect climate policy:

- reducing GHG emissions from agriculture through measures to increase yields;
- a 32% reduction in ammonia emissions from agriculture by 2030;
- enhancing carbon sequestration (by increasing soil organic carbon stocks and biomass);
- improving the gross nutrient balance of the agricultural area;
- the circular use of plant by-products in soil management and biomass-based agriculture;
- launching pilot plants to demonstrate innovations in the biomass-based economy;
- increasing the size and proportion of areas covered by agri-environmental programs out of all agricultural areas;
- production of renewable energy of agricultural origin through the rational use of by-products;
- encouraging climate protection investments and agrotechnical solutions through producer cooperation.

Long-term course of action

By 2050, the goal is to fully integrate climate change into agricultural policies and practices as a precondition, taking into account decarbonization requirements and actual changes in climatic conditions.

GHG emission reduction roadmap to 2050

The purpose of the forecast of GHG emissions from agriculture is to show how different policy scenarios influence the development of anthropogenic emissions. The calculations are based on the latest National Inventory Report of 2018. The endpoint of the forecast is 2050, but it also includes information on intermediate dates.

The following pollutant sources have been calculated for the estimation of GHG emissions from agricultural sources: methane from digestion, methane from manure treatment, direct nitrous oxide from manure treatment, indirect nitrous oxide from manure treatment, direct nitrous oxide from land use, direct nitrous oxide from land use, land use methane from rice cultivation, CO_2 from liming, CO_2 from urea-based fertilizers and CO_2 from other carbon fertilizers.

The model predicts manure use based on agricultural areas as well as policy measures that determine the use of inorganic or organic fertilizers and the amount of manure used (e.g., using precision agricultural techniques). The model also predicts livestock trends and agricultural waste management practices (e.g., manure collection and use).

For livestock, methane emissions are calculated based on the tier 1 methodology of the national inventory report. Total methane emissions from livestock can be estimated by summing methane emissions from manure treatment and methane emissions from enteric fermentation. In the latter, methane emissions are caused by digestive processes and gases emitted by animals. In the former case, emissions from manure treatment can be calculated by multiplying the number of animals (e.g. pigs) by the manure production factor and the methane emission factors used. Historical time series were used by the model to ensure consistency between simulation results and reference emissions, and to account for changes in animal husbandry practices (e.g., feeding).

Two scenarios have been developed for the model, based on assumptions about the macroeconomic environment, food consumption, demographic change and the implementation of policy measures. (Figure 40)

BAU Scenario: It builds on past measures to reduce GHG emissions from agriculture by the end of 2020. The basic assumption of the scenario is that the current free trade agreements will remain in force, the economic embargo against Russia will end in 2025, and eating habits will not change significantly. According to the scenario, the livestock will gradually increase on a market basis along with the use of nitrogen fertilizer. As a result of climate change, the yields of spring crops (maize, sunflowers) will decrease, while higher yields are expected for autumn crops (wheat, barley, rapeseed). According to the scenario, the slow, steady growth of GHG emissions started in 2011 will continue until 2050. Emissions are projected to reach 7.679 million tons of CO_2eq/year by 2050 under the BAU scenario, which, despite a steady increase, is only 64.7% of agricultural GHG emissions in 1985.

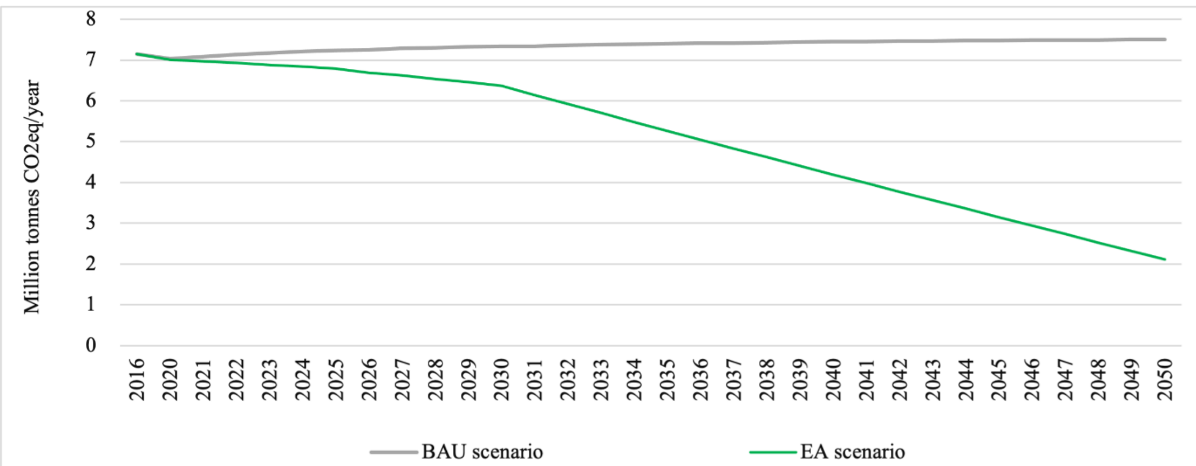
With subsidies and on a market basis, precision farming and Agriculture 4.0 is gaining ground, i.e., solutions for remote sensing of the water, nutrient, pathogen and environmental stress status of cultivated crops and the possibility of precision interventions. In animal husbandry precision farming and Agriculture 4.0 provides solutions for targeted interventions based on continuous animal health, nutrient supply and performance monitoring.

EA Scenario: The scenario includes measures and innovative technological solutions that are in the research and experimental phase, but their implementation is conceivable - in case of appropriate EU and domestic regulations.

Possible measures include restricting the use of nitrogen fertilizers by influencing prices, ending subsidies for beef cattle farming, tightening up the way fertilizer is applied, and state-subsidized cattle selection programs. This includes awareness-raising actions to change eating habits and possible administrative measures that could lead to a reduction in meat and milk consumption.

In addition, innovation must play a key role in the decarbonization of the agricultural sector, as a result of which the sector will undergo a profound structural transformation. From the beginning of the 2030s entry into the digital age of agriculture will take place. As a result of a profound transformation based on innovation, a sustainable intensification of agricultural production will be reached, which could enable to produce up to 70% more food in 2050 in a more environmentally and climate-friendly way than at present.

Implementing the BAU scenario would mean that emissions in the sector would increase by 8.4% by 2050, from 7.085 million tons of CO_2eq/year in 2020 to 7.679 million tons of CO_2eq/year. In contrast, if the EA scenario is realized, GHG emissions from the agricultural sector are expected to decrease by 70.46% by 2050, i.e. from 7.085 million tons of CO_2eq/year in 2020 to 2.093 million tons of CO_2eq/year.



Source: Eurostat, own modelling

Figure 40 – Expected change of GHG emissions in the agricultural sector between 2016 and 2050 in the event of the realization of the BAU and EA scenarios

Under the EA scenario, the greatest GHG emission reduction potential arises from a substantial structural transformation; By 2050, at least 30% of the protein, carbohydrate, fat and bioactive needs of food and compound feed production will be produced in closed-system industrial fermenters, with extraction of bred yeast and unicellular algae from biomass, with a net climate-neutral balance, using renewable energy. This will allow the livestock sector to increase or partially replace the production of protein, fat and carbohydrate feedstocks with climate-neutral technologies.

Further significant reductions in GHG emissions can be predicted from soil emissions, with the use of nitrogen fertilizer application through precision farming (continuous nitrogen (N) intake adapted to real plant nutrient supply) and innovations to date (development of functional N-fertilizers not available for soil micro-organisms that can only be used by higher plants, combining urea and other carbon fertilizers with biologically treated, continuously tested and composted sewage sludge and composted sludge remaining after biogasification). The composition of sewage sludge is not constant and therefore the risk is high due to contaminants that remain in sewage sludge or sewage sludge compost (heavy metals, drug residues, pesticides, etc.) during biological treatment, therefore continuous testing is recommended. In particular, zinc can become dangerously enriched and, from there, can easily enter the crops grown through the soil and thus to higher levels of the food chain. However, emissions could fall by 90% from 3.639 million tons of CO_2eq/year in 2020 to 0.364 million tons of CO_2eq/year by 2050.

According to experts, the use of organic manure is mainly needed on arable land for nutrient replenishment. Proper organic matter management is an important condition for competitive and environmentally conscious agricultural production, so it is crucial how producers manage by-products, e.g. using straw and manure. The effects of the energy utilization of agricultural raw materials (biomass) directly and indirectly affect all nearly 180,000 Hungarian farmers with regard to the nutrient replenishment of soils. If no adequate nutrient supply provided to the soil, the biological activity and biota of the soil is not maintained and the humus levels are not increased, the soil will not be able to regenerate and, as a result, yields will fall drastically in the long run.

In addition to serving the needs of other sectors, agriculture must also fulfill its own greening goals and tasks. The EU’s Farm to Fork strategy (which, together with the Biodiversity Strategy, serves the objectives of the new EGD) also expects farmers to significantly reduce their use of fertilizers: they must reduce the amount of fertilizer used by 20% by 2030, so the demand for manure is expected to increase within the sector as well.

The application of organic fertilizers and the management of organic manure must therefore be part of precision farming, precisely adapted to current crop needs, both in time and quantity. And this need must be reflected in stricter regulation of organic manure management and support policy. If the measures proposed above are taken and successfully implemented, current emissions of 1.121 million tons CO_2eq/year from fertilizer treatment could be reduced by 82% to 0.200 million tons CO_2eq /year by 2050 using plant-specific and functional composite fertilizers.

Within the agricultural sector, the smallest emission reductions are expected in the livestock sector, where emissions from digestion will decrease from 2.093 million tons CO_2eq/year in 2020 to 1.429 million tons CO_2eq/year by 2050. Although this represents almost 32% lower GHG emissions compared to the base year of 2020, it does not automatically mean a reduction in livestock. The increase in the proportion of industrial protein production, feed innovations resulting in lower enteric methane emissions, the intensive use of precision animal husbandry and the Agriculture 5.0 toolkit offer the potential to reduce GHG emissions even with increasing livestock.

GHG emissions from more emission-marginal inventory sectors (rice cultivation, liming, urea-based fertilizers and other carbon-based fertilizers) are expected to total 0.100 million tons of CO_2eq/year in 2050.

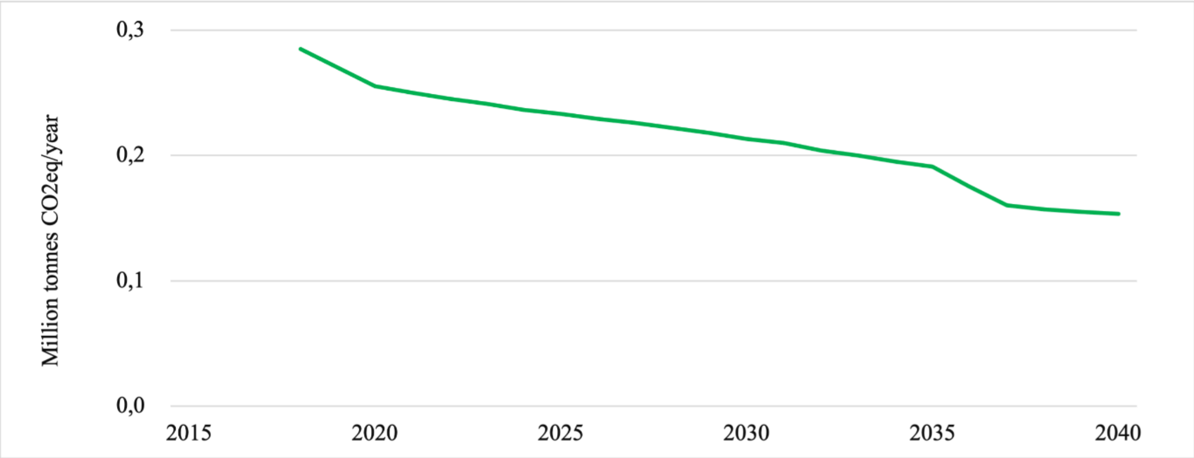
4.2.4. Land use, land use change and forestry (LULUCF)

Strengths	**Weaknesses**
Well-regulated, sustainable forest management. Even with the low forest cover of the country, significant level of carbon sequestration. Continuation of the afforestation program, faster increase of the country's wooded area, climate-conscious and sustainable afforestation. Coordinated maintenance and development of the economic, protection and recreational functions of forests.	Significant investment and support costs. Significant need for technology and human resource development. Significant need for political and other decision-making commitment. Planning ahead for 10-20 years to offset the effects of climate change.
Opportunities	**Threats**
Further strengthening close-to-nature forest management in forests of native tree species. Increasing the use of Georgraphic Information System (GIS) tools and methods. Maintaining and, if possible, increasing the CO_2 absorption capacity of our forests. Maintaining a stock structure that provides the best possible CO_2balance and takes into account biodiversity considerations. Use of wood and new processing technologies for long-term storage of absorbed CO_2.	Too rapid climate change, increase in forest damage, deterioration of forests. Significant increase in the demand for wood biomass for energy purposes. Lack of political will, funds and measures. By increasing protection levels, areas and restrictions, the use of natural raw materials, which also store coal, may be jeopardized by distorting the triple function of forests for protection, economy and public welfare. In some parts of the country, high wildlife densities, together with the effects of climate change, threaten the survival of forest stocks.

Table 8 – SWOT analysis of the LULUCF sector

Developments and main trends in past emissions

Forests continue to play a huge role in sequestering atmospheric CO_2 from human activities. Figure 41 demonstrates that the non-forest land use, land use change sector will be more of a GHG emitter in the future, so forests within the sector will be responsible for 100% of net CO_2 sequestration.



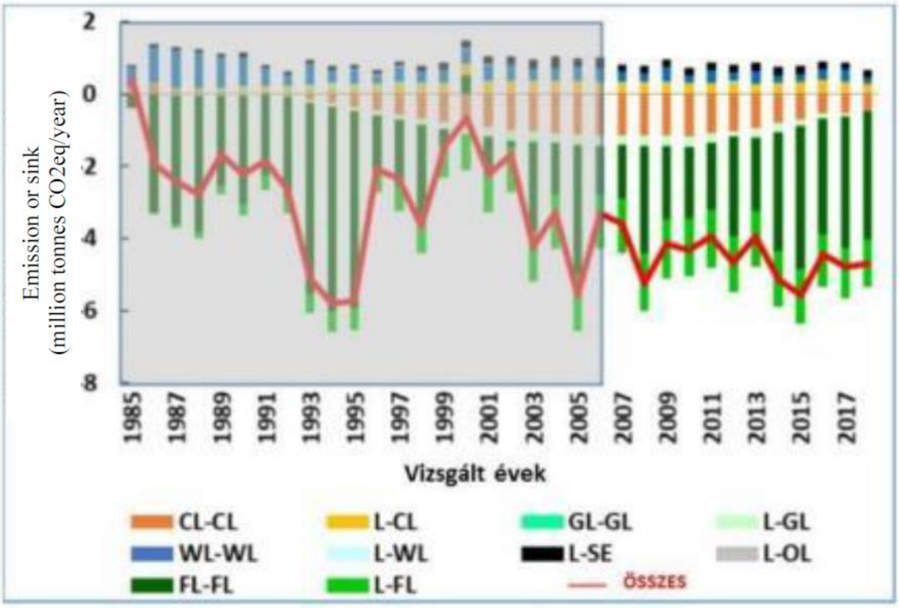
Source: Somogyi, Z. (2019): Projections for the LULUCF sector under the Monitoring Mechanism Regulation, NAIK ERTI.

Figure 41 – Net CO2 and 'non-CO2' emissions of the LULUC sector between 2020 and 2040

Forests contribute to mitigating the effects of climate change not only through the sequestration of significant amounts of atmospheric CO2, but also through its temporary or permanent storage, the replacement of fossil fuels and their beneficial micro-, meso- and macroclimatic effects.

The LULUCF sector has been considered a GHG sink overall in recent decades. However, there was more output from agriculture than this absorption, so the AFOLU sector (agriculture, forestry and other land use), which manages the two sectors together, was an overall net emitter in 2018. At the same time, an important precondition for Hungary's climate neutrality, is for the AFOLU sector to become a net CO2 sink by 2050, to the greatest extent possible.

As discussed above, the **main reason for the net sequestration of the LULUCF sector is the substantial CO_2 absorption of forests, which has been driven by significant afforestation and sustainable forest management in recent decades.** The net absorption of the sector fluctuated significantly between 1985 and 2018, with an average annual absorption rate of 3.6 million tons of CO_2eq. According to the latest available data, in 2018, forests sequestered 4.4 million tons of CO_2. (Figure 42)



Explanation: The emission data is in the positive range of the vertical axis and the sequestration data is in the negative range. Abbreviations: FL: forest; CL: arable land; SA-CL: set-aside, fallow; GL: pasture in use; SA-GL: set-aside pasture, lawn; WL: wetlands; SE: settlements, infrastructure; OL: other areas

Source: National Inventory Report 1985-2018, Hungary

Figure 42 – Estimated GHG emission and absorption trends in the LULUCF sector between 1985 and 2018

In addition to forests, temperate grasslands also play a role in sequestering CO_2, despite the risk of self-ignition of wet grasslands and peat soils.

Development policy objectives to preserve the absorption capacity of the LULUCF sector

During "Climate Breakfast" with representatives of civil society organizations and relevant industries, it was agreed that forest biomass could contribute to fossil fuel substitution and carbon sequestration through wood products and sustainable forest management. The basic condition for this is that afforestation should be more climate-conscious, i.e., tree species that are more resistant to climate change should be preferred, should be used and, where possible, the so-called transition to perennial forest management should be supported.

Gradual change of management in order to preserve the absorption capacity and biodiversity of forests:

Gradual transition from felling to perennial forest management in close-to-nature forests and in forests of native tree species where justified and feasible.

- Logging or spatial management: 50% of Hungary's forests are non-native and a significant proportion of such forests are almost monocultural, but efforts must be made to reduce the associated soil degradation and support natural regeneration.
- Perennial forest management: the creation of mixed, stable forests of multi-aged, leveled, diverse structures and site-specific tree species in near-natural habitats where our native tree species live in natural associations and where this is supported by other considerations.

According to paleobotanical research, the forest cover of the Carpathian Basin was approximately 40% approx. 1000 years ago. But even at end of World War I, there was a high forest cover of around 27%, which fell to 11.8% by the end of World War II. As a result, Hungary has become the fourth poorest country in Europe in terms of forests and trees. Since then, the forest cover rate has improved significantly and currently it is above 20%. The 20% forest cover means that our forests occupy approximately 1.9-2.0 million hectares of Hungary's 9.3 million hectares territory.

However, the National Reforestation Program and the National Forest Strategy (NFS) set the goal of further increasing forest areas, as a result of which Hungary will reach 27% of forest cover level again by 2050. This will require afforestation of an additional 350,000-400,000 hectares, without counting in the legally non-forest wooded areas, while obviously continuing to manage the existing forests in a sustainable way, taking greater account of climate policy and biodiversity conservation objectives.

Links with agricultural and rural development policies

Among the forestry policies of the Hungarian Rural Development Program, there are a number of measures that help forests to adapt to climate change and increase their carbon sequestration capacity. It is important to stress that adaptation measures are crucial for the conservation of forest carbon stocks. The expected drier and warmer climate in many forest areas can lead to reduced growth, deterioration of tree health, multiplication of pests, and, in unfavorable cases, extinction processes, which should be prevented if possible. The measures related to climate change in the 2014-2020 rural development period should therefore be maintained in the 2021-2027 period, and their expansion is even planned.

The current Forest Act prioritizes the increase of forest areas that are more resistant to the effects of climate change, including continuous forest cover, and, in the case of native tree species, the establishment of mixed tree stocks close to nature. In order to increase the wooded area of the country, a national afforestation program has been announced, which will also mobilize the population to increase the wooded area. In addition to the tree planting programs, the unit prices of the afforestation measure of the rural development program, the period and the amount of income replacement support were significantly increased.

Other relevant measures:

- increased protection of forests, prevention of forest destruction, forest fires, mitigation of adverse effects;
- the development of professional forest management, which provides high-quality wood raw material and the wood industry capable of processing wood as much as possible, the replacement of raw materials and products produced with higher energy consumption and high GHG emissions;
- full integration of climate change as a precondition into forestry policy.

Long-term course of action

By 2050, climate change as a boundary condition must be fully integrated into forestry policies and practices, taking into account decarbonization requirements and actual climate change.

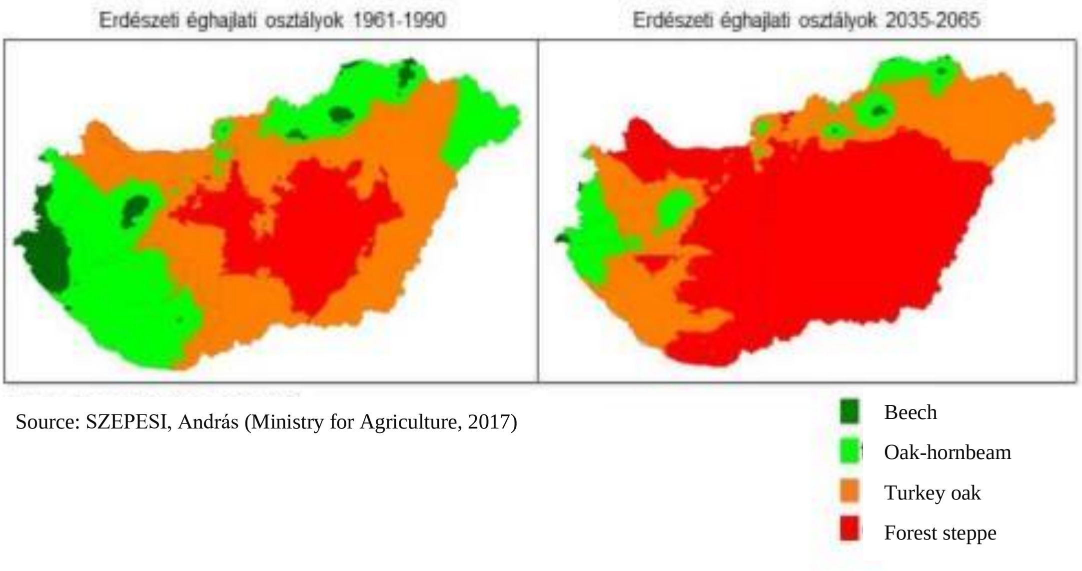
GHG emission reduction roadmap to 2050

The GEM model predicts emissions from forest areas, non-cultivated areas (fallow), agricultural and residential areas. Emissions from soil are calculated as the sum of emissions from each of the four land use categories.

Emissions from the four land use categories are calculated by multiplying the given land use stock by an emission factor. Land use and emission factors are calibrated based on data from the national GHG inventory report.

Emissions from the forest area - areas registered as forest parcels, free-range forests in the National Forest Stock Database, as well as woody plantations and other forest tree species meeting forest definitions in accordance with international forest definitions – are calculated by the model as the sum of (1) forest emissions using the forest stock and the emission factor for the forest area, (2) the decrease in carbon sequestration due to tree aging, and (3) the increase in carbon sequestration capacity due to afforestation. Emission projections (2) and (3) were determined using the BAU and EA scenarios.

BAU scenario: It will be realized if between 2020 and 2050, based on the experience of recent years, a moderate afforestation will take place (3500 ha/year), which will not allow the goals set in the NFS to be met. As a result, forest cover will not increase significantly, and as the average age of forests increases, the mortality rate of tree stocks will increase. Gradually, old forests, which are decomposing their organic matter and becoming CO_2 emitters, are becoming predominant. In addition, the increase in the frequency of climate change-related habitat "aridification" and extreme weather events will result in the fragmentation of country's currently closed mid-mountain forests, and a significant part of Hungary will become a forest-steppe during the 21st century (Figure 43).



Source: Forestry Science Institute, 2017

Figure 43 – Expected change of forest cover and forest ecosystems by 2065 if the BAU scenario is realized

EA scenario: if implemented this scenario allows to achieve the targets of the National Afforestation Program and the NFS, i.e., the forest cover rate will increase from the current 20.8% to 27% by 2050, and the annual "net" afforestation will reach 13,000 hectares.

Under the EA scenario, similarly to agriculture, digitization and automation tools are gaining more and more ground in forestry, and in the afforestation programs, predominantly more drought-tolerant propagating materials of our native tree species are used.

In the area of support policy, consideration should be given to the fact that, under the international emissions trading scheme, part of the revenue from CO_2 allowance trading should be used for natural carbon sequestration, afforestation, long-term forest maintenance and the development emissions-optimal stock structure, that is climate resilient. Achieving these goals goes beyond the utilization restrictions still expected of forest owners, so the loss of expected economic benefits must be compensated. Spending part of the revenues from EU ETS in the forestry sector would be a significant source of increasing Hungary's forest cover.

4.2.5. Waste management

Strengths	**Weaknesses**
Progress towards a green economy. Job creation potential. Encouraging investment. Strengthening the innovation linkages between producers and waste managers.	Current recovery capacity is low in regional comparison. The management capacities required to meet the Circular Economy objectives are not fully available. Landfilling is widespread as it is still the cheapest solution. Quality of public service varies by region
Opportunities	**Threats**
Strengthening cooperation between manufacturers, waste managers, research centers and universities in the field of research and development. Development of domestic utilization capacities. Significant absorption capacity of agriculture for compost. Development of new consumption habits, continuous awareness-raising of the population. Greater involvement of manufacturers in funding due to extended producer responsibility. Advantage of local/nearby capacities due to the collapse of the secondary raw materials sector market	Passing on increased producer costs to consumers. - low solvency. Without rapid action, recovery capacities could move to neighboring countries. There is no qualitative development of previously built capacities. Lack of funding for investments. The market for secondary raw materials is shrinking as a result of the economic crisis.

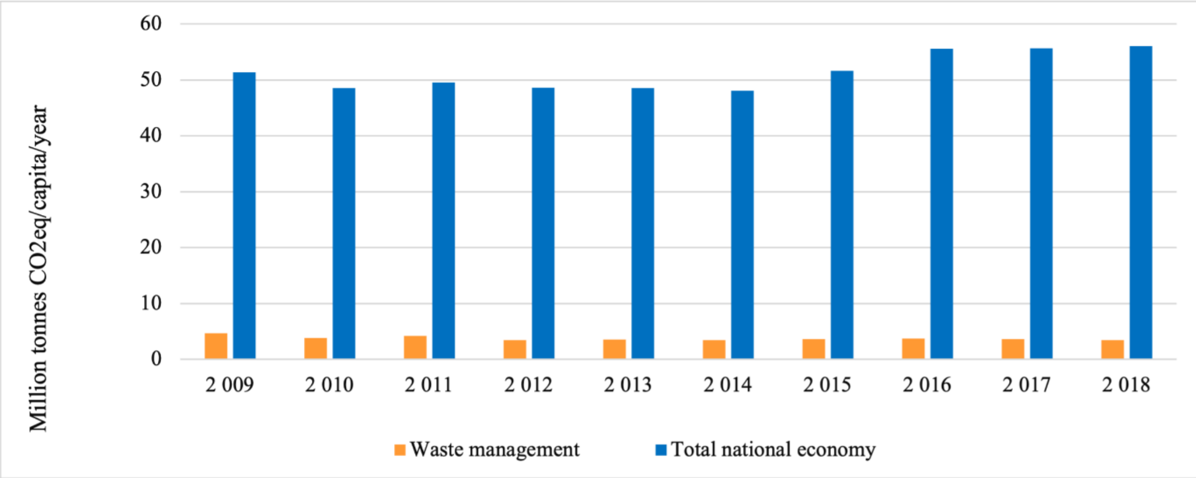
Table 9 – SWOT analysis of the waste sector

GHG emission trends

Since Hungary's accession to the EU, significant progress has been made in the field of waste management, which led to GHG reductions in the sector. The previous uncontrolled, approx. 2,200 “landfills” operating or already abandoned without proper insulation and depot gas treatment were closed by 2009, and their recultivation took place by 2015. Based on 2018 data, 75 "B3"[26] landfill operating permits comply with all current EU regulations, and technological equipment has been installed for the collection and treatment of approximately 40% methane-containing landfill gas, which serve energy recovery and/or flaring of methane in the landfill gas.

In Hungary, GHG emissions from waste-related activities and waste management accounted for 5.9% of total GHG emissions in 2018, with emissions from the sector showing a declining trend over the last 10 years (Figure 44). The main reason for this is the declining rate of methane-producing landfilling, while the amount of waste per capita stagnates with a small variance (1%).

[26] Mixed landfill for non-hazardous waste (with significant organic and inorganic content)



Source: Eurostat

Figure 44 – GHG emissions from waste management relative to total emission in Hungary (million tons CO_2eq.capita/year)

In 2018, landfilling accounted for the majority of emissions (84%) under the waste management sector which also include **wastewater treatment** (11%), **composting and other biological treatment** (4%) and **non-energy waste incineration** (1%). In contrast to other emitting sectors, emissions from waste management are 3% higher than in the base year of 2004. However, emission growth stopped in the early 2000s and then fell by 19% between 2005 and 2017. In landfills, waste decomposes over many years, meaning that waste disposed of years ago also has an impact on current emissions. However, the quantities of waste landfilled has decreased significantly over the last 10 years and the composition of landfilled waste has also changed (e.g., separate collection of green and paper waste has reduced the amount of biodegradable waste landfilled), resulting in reduced GHGs emissions. **Emissions from wastewater treatment** has also declined which is explained by the increasing number of dwellings connected to the public sewer and the increasing capacity of closed sludge fermenters built at larger wastewater treatment plants.

Development policy objectives

The EU legislation package on the **circular economy** came into force on 2 December 2015, defines the strategic plans for the next 10-15 years. The basis for future waste management is determined by this approach, which prioritizes sustainability and cooperation between industry through the development of a more material- and energy-efficient economic model. Putting the circular economy into practice will help reduce GHG emissions. The legislative package has tightened up the existing waste management targets and identified other specific sub-targets. In order to achieve these goals, Hungary needs to significantly increase the amount of separately collected and treated waste in the coming years and minimize landfilling.

Another important element is Directive 2019/904/EU of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (Single-Use Plastics Directive (SUP Directive)), i.e. it aims to prevent and reduce generation disposable plastics. The SUP Directive requires Member States to take specific prohibitive, restrictive and regulatory measures on packaging and non-packaging, single-use and oxidatively degradable plastic products and their waste. The most ambitious requirements include the targets for plastic beverage bottles in the SUP Directive. Under the specific targets, 77% of plastic beverage bottles should be collected separately by 2025 and

90% by 2029, with the ultimate goal of making the recycling process more efficient. Another ambitious requirement is that, by 2025, the beverage bottles should be made from 25% secondary raw materials made from waste, and plastic beverage bottles should be made from 30% secondary raw materials by 2030. To achieve this, the SUP Directive proposes the introduction of a redemption fee (deposit fee) system or setting a separate collection target under the extended producer responsibility scheme.

Currently, 84% of the sector's GHG emissions come from landfills. According to the "circular economy" package, by 2035 a maximum of 10% of municipal waste generated can be landfilled (with a derogation of 25%), which means that, as a result of material flow calculations, only slag/residual waste from burning or energy generation can be disposed of in the future. This results in huge GHG savings, as the amount of slag/residue generated during energy recovery does not need to be included in the amount of landfilled municipal waste.

Another high-impact provision in the legislation-package is that it introduces additional obligations for the period 2025-2035 (a derogation of up to 5 years may be requested under certain conditions):

a) By 2025, the amount of recycled municipal waste and waste prepared for re-use should be increased to a minimum of 55% by weight (with a derogation of 50%);

b) By 2030, the amount of recycled municipal waste and waste prepared for re-use should be increased to a minimum of 60% by weight (with a derogation of 55%);

c) By 2035, the amount of recycled municipal waste and waste prepared for re-use should be increased to a minimum of 65% by weight (with a derogation of 60%).

In order to prohibit and restrict the sales of single-use plastics in the framework of the transition to a circular economy, **Hungary was among the first to adopt an act on the transposition of the SUP Directive** (Act XCI of 2020) containing enabling provision for government decree-level regulation. The technical notification of the government decree is in progress, it can be promulgated after its completion and it will take effect from 1 July 2021.

One of the biggest challenges in designing the National Waste Management Strategy currently under development and the new National Waste Management Plan, is that the transformation of the future waste composition is very difficult to plan, as producers and distributors are now radically transforming the packaging and other parameters of their products, from a technology and material use perspective.

The proportion of biodegradable waste (including a significant part of the fine fraction) in the current composition of municipal waste exceeds 30%. The treatment of that portion of the waste stream is determinant to achieve the recovery targets of the circular economy and for the sector's GHG emissions. Compliance with the separate collection obligation for biowaste must be ensured by 31 December 2023.

During the stakeholder consultation held under the preparation of this Strategy, industry and professional organizations affirmed their commitment to prioritize the reuse and recovery of material, the reduction of biowaste and organizing the treatment of the small remaining waste. This is supported by sector guides to good practice developed in collaboration with industry in the framework of the National Food Chain Safety Agency's National Food Waste Prevention Program called “Without leftovers”.

In the field of food retail, several chain stores operating in Hungary are already launching their own waste management programs.

There is also strong interest in the development of biogas plants. According to the provisions of the Circular Economy Directive package, energy recovery or fuel production do not contribute to the achievement of recovery targets, but it is expected to be clarified whether the utilization of fermented residues at the end of the anaerobic process as soil improvers can be accounted for. This can practically mean that if 20-30 units of the 100 units of material entering the energy recovery are utilized as slag or biogas residues, then the 20-30 units can be taken into account in the fulfillment of the circular economy targets.

From the point of view of GHG emissions, aerobic composting of biodegradable waste is more advantageous compared to anaerobic treatment, because in case of improper sludge treatment, significant CO_2 and methane are still released from the residue. This is technologically manageable but will definitely require special attention in the future.

For the above reasons, the sector's GHG emissions will basically be determined by the following two main aspects:

- The level of treatment and recovery of **biodegradable, compostable waste** (compost) must be increased. Closed technology anaerobic treatment technologies (biogas[27], fermentation) do not sufficiently serve the goals of the circular strategy. Although energy recovery can play an important role and create synergies with EU energy and climate policy, it can only be accepted if it follows the principle of the EU waste hierarchy.
- Expanding either recyclable packaging or selective collection to residential homes will generate multiple collection and transportation needs compared to the current one, which will increase **transportation-related GHG emissions**.

GHG emission reductions roadmap to 2050

In the first phase of the modeling four different scenario versions were developed based on the policy goals, collection and treatment rates and technology, assuming that Hungary complies with the EU, i.e., makes the necessary investments in the next 10 years. A version selected on the basis of cost-effectiveness considerations and to meet the requirements of the Directive has been integrated into the GEM model to **achieve climate policy targets**, i.e., a lower-cost GHG emission reduction pathway. For the quantitative variants preceding the GEM model, the highest possible home composting prevalence was assumed (based on international, already realized rates) in terms of cost-effectiveness, that does not entail transport and operating costs. The production of Refuse Derived Fuel (RDF) does not serve the purposes of the circular economy and is expected to decrease in terms of energy and cost savings.

Among the main sectors within waste management (municipal, agricultural, industrial), focus was given to **municipal waste** on one hand due to the impact on GHG and on the other hand the challenges of the circular economy directive, since the role of the state is decisive here. Quantitative forecasting of **industrial waste** follows the industrial performance of the GEM model, with treatment modality rates shifting toward full recovery by 2050. In this sector, the responsibility also lies at the EU level with waste producers. The amount of **agricultural waste** also varies in proportion to the agricultural performance of the GEM model; similar to industrial waste, the agriculture sector will be tasked with maximizing material recovery by 2050.

[27] Rheinischen Friedrich-Wilhelms-Universitat Phd. dissertation: Nguyen Thanh Phong: Greenhouse Gas Emissions from Composting and Anaerobic Digestion Plants (2012)

Eventually, one scenario was selected optimized for cost-effectiveness, which became the proposed scenario in this strategy and was further processed in the GEM and TIMES models.

Accordingly, two versions have been developed:

- **BAU scenario:** takes into account the effects of the measures adopted so far. In this scenario, all waste generation and management options will remain at the current level and will only change in proportion to population and GDP change.
- **EA scenario:** aims to achieve climate neutrality and waste management meeting the expectations of the circular economy will be achieved by 2030.

It is important to note that the third applied, EA scenario, the LA scenario that was used for the other sectors is the same as the EA scenario for the waste sector, as the circular directives requires the achievement of the sectoral targets by 2030 and 2035, respectively, which at the same time, also serve the 2050 climate targets.

In order to achieve the target of a very high recycling rate, biodegradable and compostable waste must be treated primarily through composting technology, which can be used as a soil improver. Currently, aerobic composting technologies represent the lowest GHG emissions within different biological treatments, so this practice was integrated in the EA scenario. In addition to central, mechanized composting plants, it is also very important to increase residential composting capacities.

Innovative waste management technologies and solutions

- "Smart" solutions: construction of radio-frequency identifiers for residential and institutional collection containers, container saturation signaling systems for industrial waste, development of real-time optimization software, tracking in case of redemption fee packages, waste collection vending machines.
- Development of solutions accompanied by alternative energy utilization (pyrolysis, depolymerization, etc.) by maximizing material utilization (production of chemical secondary raw materials).
- Dissemination of home composting: extensive awareness raising about the correct use of composting bins.
- Development of industrial production processes towards waste-free processes: food industry, automotive industry, chemical industry.
- Encourage collaboration between universities, research centers and sectors.

To achieve 65% material **recovery rate** by 2035, all packaging material (i.e., **metals, plastics, paper, glass, etc.)** must be collected. A **redemption system for plastic bottles with an extremely high collection rate of over 90%, or a selective collection at least four times more frequent than at present,** is also possible, but a combination of these is more likely.

In the case of GHG emissions, the **growing waste transport demand** was taken into account. The excess emission of this activity is accounted for in the **transport sector** by the TIMES model (the waste transport performance was 29.957 million km in 2019, which is expected to increase to 45.510 million km/year in 2030 and 44.347 million km/year in 2050). This is explained by the specific transposition and detailed regulation of the waste management directives aimed at the implementation of the circular economy in the Member States is still in progress.

Material utilization results in huge savings in terms of GHG emissions[28], as primary raw materials are replaced with secondary ones.

[28] Greenhouse gas emissions of waste management processes and options: A case study (Waste Management & Research, May 2016)

GHG potential of material recovery (illustrative examples):

- Recovery of 1 ton of plastic waste = 2300 kg CO2eq savings
- Recovery of 1 ton of metal waste = 1750 kg CO2eq savings
- Recovery of 1 ton of paper waste = 795 kg CO2eq savings
- Recovery of 1 ton of glass waste = 529 kg CO2eq savings

In addition to significantly reducing GHG emissions in the waste management sector, the EA scenario also results in cost savings due to declining **labor demand**, especially for **industrial waste management**. The declining demand for labor by 2050 is caused by the decreasing trend in the amount of waste generated. On the one hand, the expectations placed on manufacturers will eliminate packaging that is difficult or impossible to recycle, and in the case of short-lived products, materials that simplify recycling (especially secondary raw materials) will displace current materials.

It is expected that difficult-to-handle composite packaging will disappear, auxiliaries and by-products in industrial processes will not become waste, as manufacturers will be forced to form an industrial symbiosis with activities in which the by-product of one process is used at the place of origin. Thus, activities are transferred from the waste management sector to the internal processes of producers/manufacturers, and in the waste management sector, the need for equipment and labor is drastically reduced due to the reduction of the amount of waste.

The use of redemption systems is expected to expand or become more comprehensive, replacing today's containerized waste collection systems. This frees up high-value vehicles, equipment, and labor.

The regulations of the circular economy clearly serve the drastic reduction of waste generation, and it can be rightly assumed that after 2030-2035 further international regulations and conventions will be concluded in order to prevent the generation of waste.

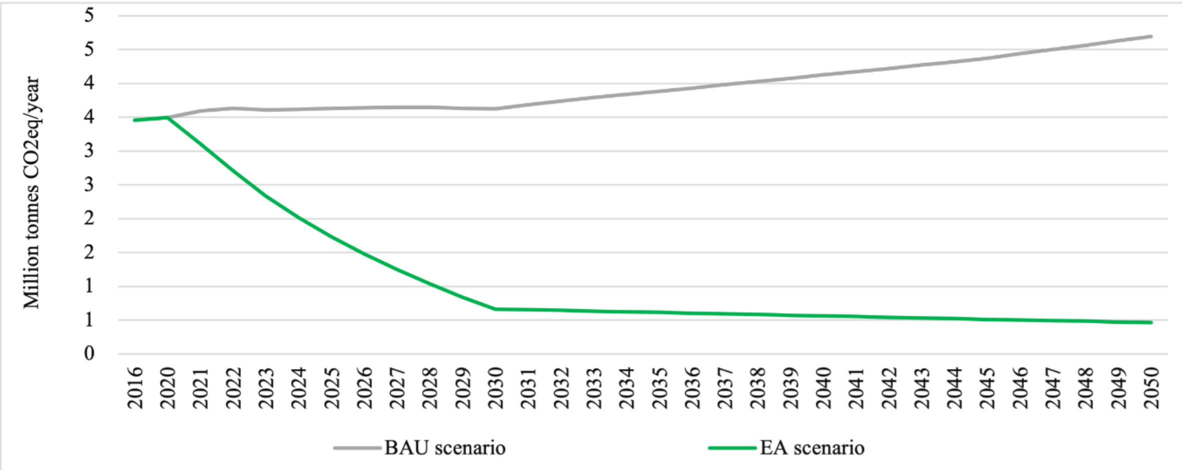
The table below illustrates the difference between the BAU and the EA scenario in terms of costs.

	2030	**2050**	**2030**	**2050**
At 2020 price levels (billion HUF)	**billion HUF/year (EA - BAU difference)**	**billion HUF/year (EA - BAU difference)**	**% (EA / BAU rate)**	**% (EA / BAU rate)**
Total costs of waste management	**127,18**	**-276,70**	**112,55%**	**76,86%**
Total investments costs	**189, 10**	**-124, 78**	**123,92%**	**86,51%**
Total investment costs of municipal waste	407,29	202,79	176,24%	134,04%
Total investment costs of industrial waste	-143, 62	-250,70	19,09%	0,00%
Total investment costs of agricultural waste	-74,56	-76,87	5,33%	1,65%
Total operation costs	**-61 92**	**-151,92**	**72,24%**	**44,01%**
Total operation costs of municipal waste	-0,29	-37,00	99,80%	76,33%
Total operation costs of industrial waste	-56,91	-110,06	26,96%	0,00%
Total operation costs of agricultural waste	-4,718	-4,86	5,26%	1,63%

Table 10 - Costs in the waste sector between 2030 and 2050 according to each scenario (HUF billion)

According to the results shown in the table above, the investment costs required for the introduction of a circular economy by 2030 are significantly higher for municipal waste in the case of the EA scenario (2030: ~ 407 billion HUF, 2050: 202 billion HUF) compared to the BAU scenario. This can be attributed to the replacement and average investment costs of the equipment needed for the transformation (construction of incineration and pre-treatment capacities), while operating costs are already declining. In the case of industrial waste, the costs of the waste management sector in the current sense will be eliminated (therefore 0% compared to the BAU scenario). Overall, this offsets the growing need for investment in case of municipal waste treatment, and the absence of industrial waste treatment results in net savings for the sector as a whole.

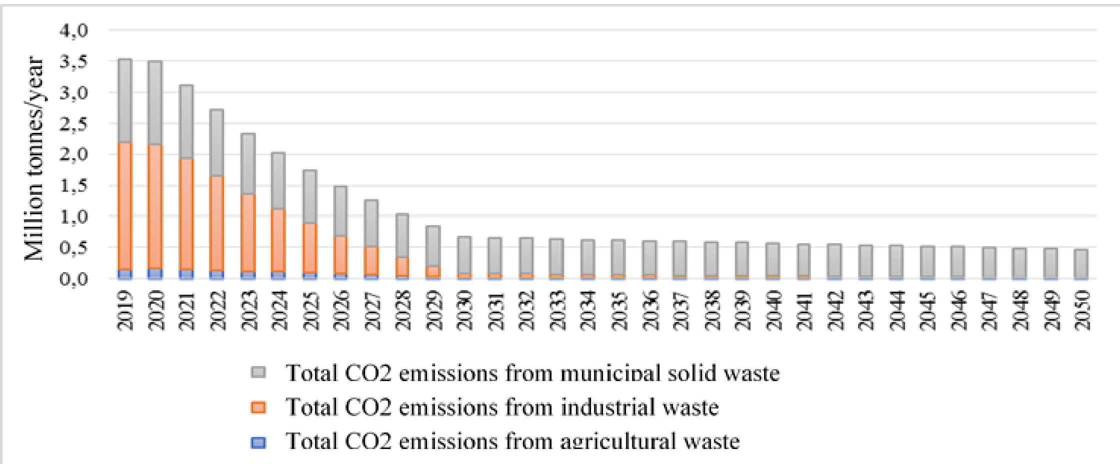
The GHG emission projection for the waste sector until 2050 under each scenario is illustrated in Figure 45. According to this, the sector's output will increase linearly with GDP growth in the BAU scenario. In contrast, in the EA scenario, emissions are reduced to one-tenth of the base value.



Source: Eurostat, own modelling

Figure 45 – Forecast of GHG emissions from waste management according to the BAU and EA scenarios

The emission forecast for the sub-sectors within waste management for the EA scenario is presented in **Hiba! A hivatkozási forrás nem található.**.



Source: own modelling results

Figure 46 – Forecast of GHG emissions from waste management by subsector according to the EA scenario

As shown in the figure, full recycle of industrial waste is expected. **Mandatory use of secondary raw materials** will become an integral part of industrial material management and will generate a demand market for secondary raw material. The responsibilities of the circular economy directives fall on the producers, which is expected to be further enhanced by regulatory and voluntary commitments of industries. A significant part of the materials currently treated as waste will not appear as waste in the future or will remain the property of the producer/manufacturer, e.g. the pallets and packaging used in logistics are only "lent" to the buyer and taken back by the producer, and then reused in his own production and logistics processes. The economic basis for this approach has already been laid down in the form of a circular extended producer responsibility (EPR) fee, and the legislator's intention is to provide an economic incentive towards a real "Zero waste".

In short, the following measures need to be introduced:

- In addition to regulation, economic incentives and infrastructure development, there is a need for effective **public awareness raising** to encourage prevention, informed shopping and the disposal of waste under a new scheme.
- In addition to the existing ~ 400,000 t/year **energy utilization** of mixed municipal waste, an additional ~ 800,000 t/year new, modern, high energy efficiency (min. 60%) incinerator capacity is required.
- The share of **home and community composting** should be increased from about 55 thousand t/year to ~ 220 thousand t/year.
- A minimum of 60% of the generated waste must be diverted from the currently mixed municipal waste stream (using selective collection, a redemption system, or another selective collection scheme, or a combination of these options).
- When manufacturing and placing new products on the market, the highest possible **mandatory secondary raw material use rate should be prescribed**, which leads to net GHG savings and generates revenue for the waste sector.
- By 2050, the **full recovery of industrial waste** will be at zero-cost for the waste sector due to proper product design and the closed loop of production systems. The costs will remain within the industrial sector, not separated from product manufacturing and logistics processes (the operating and investment costs incurred have already been included in the costs of the industrial sector).

4.3. Socioeconomic impacts

Key message: The decarbonization of the Hungarian economy will deliver significant socioeconomic benefits

This Strategy assessed two main types of societal outcomes of low-carbon interventions: (i) avoided costs and added benefits and (ii) employment impacts. Among the avoided costs, avoided energy and fertilizer use (material), reduced transport-related externalities (i.e.., accidents, air pollution), and the social cost of carbon (SCC) (non-material) were estimated. Among added benefits, the increase in GDP and government revenues because of cost reductions and improved labor productivity were considered.

The economic viability of investments aimed at reducing GHG emissions has been analyzed for decades. The approach used, in most instances, has been a conventional Cost-Benefit Analysis (CBA). This takes (i) the implementation costs of projects and policies (i.e., the investment required, as well as the operation and maintenance cost) and (ii) the direct benefits generated by the same projects or policies. Moreover, CBAs are normally applied to a single project or investment and consider benefits only available for investors. These benefits are usually limited to those expressed in monetary units. Standard project-based CBAs do not assess the tangible/material and intangible, non-material benefits (or costs) of a given investment to society, regardless of if they are monetized or not. Nevertheless, investments in low carbon development are designed to tackle a societal issue such as climate change that affects many economic actors simultaneously. Investments in energy efficiency for instance, reduce energy consumption and curb emissions, while at the same time, the co-benefit of avoided energy use, reduced air pollution and health costs emerge. Therefore, to carry out a comprehensive assessment of climate mitigation interventions and socio-economic value of such investments in a coherent way, societal impacts need to be estimated. This type of extended CBA, i.e., assessing societal impacts, has become a common practice the last years in analyzing the costs and benefits of low carbon development scenarios.

4.3.1. Avoided costs and added benefits

All avoided costs and added benefits (Table 11) account for nearly half of the total investments required between 2020 and 2030 according to the EA scenario.

This indicates that **in the next 10 years, more than half of the investments required will be repaid via avoided costs**. When we consider added benefits as well (i.e., higher GDP and its impact on government revenues), **90% of the total investments required will be paid back according to the EA scenario** over the same period. When the long-term horizon up to 2050 is considered, the values of avoided costs and added benefits outweigh the investment costs. This is because a longer time frame will better capture the benefits of investments over their lifetime (i.e., the same investment reaches higher avoided costs and added benefits in the longer term).

During the period between 2030 and 2050, a higher investment need is expected, which is explained by a larger-scale emission reduction effort necessary to reach the 2050 climate neutrality target. The cost to reduce each ton of emission is increasing as the full decarbonization approaches. Therefore, under the EA scenario, the total avoided costs account for two thirds of the total investment costs by 2050. Furthermore, **the sum of avoided costs and added benefits by 2050 will be higher than the investment costs.**

It should be highlighted that the avoided costs and added benefits are expected to occur well beyond 2050. This is because the investments made between 2040 and 2050 have a lifetime that stretches beyond 2050, reaching even 2060 and 2070. The benefits emerging after 2050 were not captured in the present modeling exercises.

Concerning avoided costs, the EA scenario shows roughly equal reductions in energy costs, the SCC[29], and transport-related externalities.[30] It is estimated that the SCC in 2020 represents about 1% of GDP. With the full decarbonization of the economy by 2050, the SCC will decline to zero. While being an intangible indicator—since it is not directly linked with public and private expenses—it may indicate that Hungary and many Member States of the

[29] The Social Cost of Carbon (SCC) is a widely used proxy indictor to express the economic impacts of climate change. It indicates the marginal cost that is caused by each extra emitted ton of GHG.

[30] Transport-related externalities include the costs of accidents as well as the costs from caused noise and air pollution.

EU will move effectively toward decarbonization, and that the cost of climate change will decline when compared to the BAU scenario.

Transport-related externalities—including the cost of respiratory diseases due to air pollution, cost of noise pollution, cost of accidents, and value of time lost due to congestion—reach approximately 2% of GDP in 2020. According to the forecasts, in the case of the carbon neutrality scenarios—especially under the EA scenario—the number of vehicles will be higher. This trend will increase the demand for transport and energy consumption. Nevertheless, the shift to low-carbon vehicles will reduce the incidence of transport-related externalities on GDP by 0.2%–0.3% in the coming three decades.

Concerning added benefits, due to higher investment efforts, lower energy costs, and increased productivity, GDP is forecasted to be 21% higher under the EA scenario, compared to the BAU scenario by 2050.

Many factors impact productivity[31] in the model, such as the applied technology, energy costs, air and water quality, and infrastructure (e.g., roads). Low-carbon development reduces energy costs and emissions, which directly impacts productivity and the increase of GDP. Additional increases of GDP induce new investments and create new jobs, thus it further incentivizes economic development.

When compared to the BAU scenario, the GDP growth rate is similar until 2025 but grows faster from 2026 to 2050. This is due to net savings generated by investments, energy efficiency, and a fuel switch. The annual growth rate of GDP will be 0.11 percentage points higher in the EA than under the BAU scenario. In addition, GDP is forecasted to grow more markedly toward 2050.

ntForecasts show that the average annual growth rate between 2030 and 2050 is 0.61 percentage points higher in the EA scenario than in the BAU scenario. In 2050, the growth rate of GDP—partly driven by green investments—in the EA scenario is 7.03%, which is significantly higher compared to the BAU scenario at 1.79%.

Government revenues follow a similar trend to GDP. Since government revenues are calculated from the growth rate percentage of GDP, **higher GDP growth results in higher government revenues.** By 2050, the **additional government revenues generated by decarbonization measures will account for 47% of the investments required in the EA scenario.** This means that the expected growth in tax revenues will cover nearly half of the investments required; therefore, state stimulation at this scale will not bring additional costs for the government.

Table 11 - besides representing the demonstrable costs and benefits of the EA and LA scenarios over the 2020–2030 and 2020–2050 periods, compared to the BAU scenario - also provides information on investment cost trends and labor market impacts.

[31] The methodology of how the GEM model calculated productivity is discussed in Annex 4.

	EA scenario 2020-2030	LA scenario 2020-2030	EA scenario 2020-2050	LA scenario 2020-2050
Investment costs – billion HUF				
Agriculture	82	82	745	745
Waste management	851	852	480	476
IPPU	79	80	129	131
Energy	1 297	644	22 391	11 352
LULUCF	35	35	964	96 473
Total investment costs	**2 344**	**1 693**	**24 709**	**13 668**
Avoided costs - billion HUF				
Material	693	685	2 393	556
Avoided energy cost	*638*	*630*	*2 142*	*305*
Avoided fertilizer cost	*56*	*56*	*251*	*251*
Nonmaterial	527	279	4 993	3 441
Avoided social cost of carbon	*487*	*480*	*2 604*	*2 269*
Transport-related negative externalities	*40*	*-200*	*2 389*	*1172*
Total avoided costs	**1 221**	**964**	**7 387**	**3 997**
Added benefits – billion HUF				
Real GDP	**582**	**482**	**19 783**	**11 170**
Government revenue	**246**	**215**	**11 142**	**6 200**
Additional job creation – number of jobs				
Total net new jobs	16 283	17 962	**182 566**	**123 690**
Indirect employment creation	10 340	11 349	64 983	60 678
Direct employment creation	5 943	6 613	117 583	63 012

Table 11 – Cost-benefit analysis for the periods of 2020-2030 and 2020-2050 (Additional cost and benefits compared to the BAU scenario)

4.3.2. Job creation for the low-carbon transition

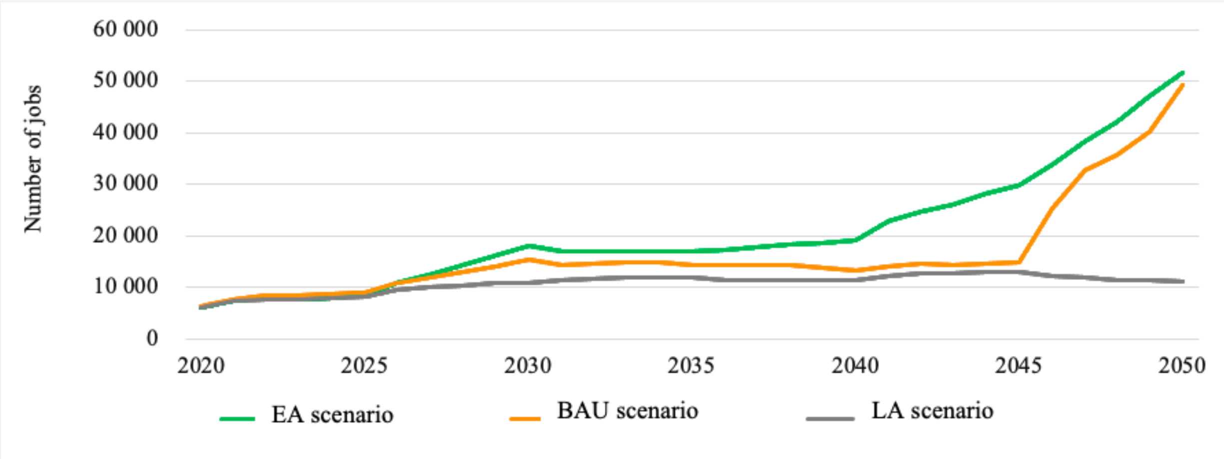
Reaching climate neutrality by 2050 would require transformational change and substantial investments in all relevant sectors in the next years and decades. Nevertheless, the process of decarbonization in all economic sectors will create considerable employment opportunities, assuring increased prosperity for the Hungarian people in the long term. This is very much needed in the context of a successful and long-term recovery from the economic crisis caused by the COVID-19 pandemic.

The employment effects of the decarbonization of selected sectors and subsectors on the Hungarian economy have been analyzed. In particular, the potential of direct net employment creation in the power sector, energy efficiency, bus transport, waste management, and reforestation, as well as indirect employment driven mainly by higher GDP and higher productivity, were the focus of the assessment. Investments in these sectors will not only create jobs in the green industries (i.e., direct jobs) but will also drive economic and employment opportunities in other economic sectors and have a spillover effect on the overall economy (indirect jobs).

Table 11 summarizes the net direct and indirect job employment opportunities that will be created by investments in decarbonizing the Hungarian economy under the EA and LA scenarios by 2050, compared to the BAU scenario. **According to the EA and LA scenarios, approximately 183,000 and 124,000 additional jobs will be created by 2050, respectively.**

Direct employment creation refers to jobs created within the country as the result of interventions in the fields of power generation, energy efficiency, public transport, waste management, and forestry in the phases of building, operation, and maintenance. Indirect employment creation is the result of macroeconomic impacts of low-carbon investments, mainly in the industrial and service sectors. For example, energy efficiency measures reduce energy costs, which is followed by increased productivity and therefore a higher GDP. The higher GDP also increases the level of consumption and investments. Employment creation is the result of higher consumption and expenditures as well as the expansion of productivity, which is caused by the accumulated impacts of investments.

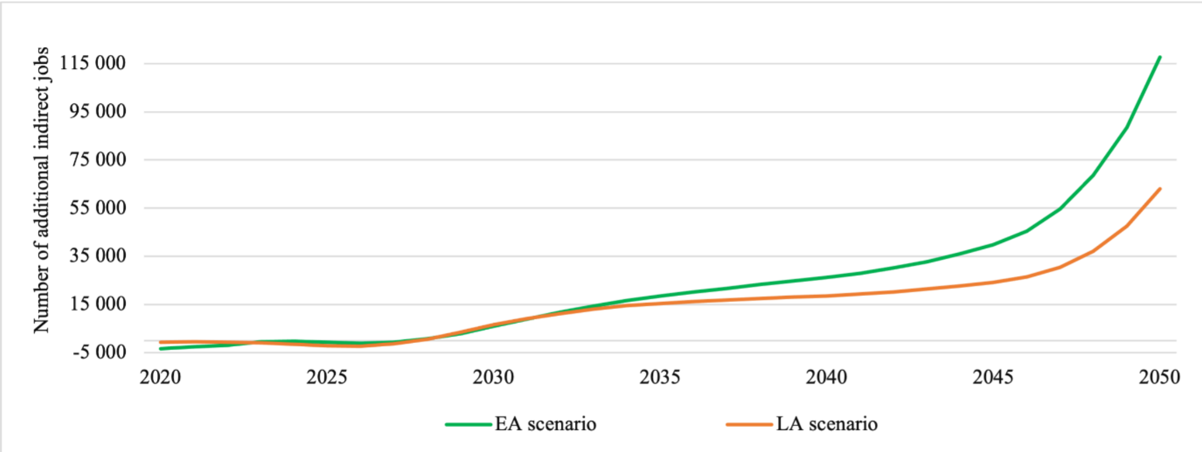
Investments related to the decarbonization of the energy sector, clean energy infrastructure, and increased renewable energy capacities **can create an additional net 41,000 (EA scenario) and 38,000 (LA scenario) direct jobs by 2050 compared to the BAU scenario.** In the LA scenario, job creation will play a prominent role from 2045 onward since this is when a significant increase in climate neutrality investments can be expected. In comparison, the EA scenario shows a more gradual approach, which brings more consistent job creation during the whole modeled period (Figure 47).



Source: own modeling result

Figure 47 – Employment in the power generation sector according to different scenarios

Figure 48 represents the development of additional jobs created under the EA and LA scenarios. As discussed earlier, **the EA scenario** shows a more progressive decarbonization pattern that **generates more jobs by 2050.**



Source: own modeling result

Figure 48 – Indirect job creation in the EA and LA scenarios compared to the BAU scenario

A well-managed consideration and planning of employment shifts is needed to ensure a socially just transition. The creation of green and direct jobs is at the heart of the socioeconomic benefits from the decarbonization of the Hungarian economy. Creating new, green, and well-paying jobs is of utmost importance in regions affected by the coal phase-out, which would contribute to the financial growth of families. Measures such as (re)training programs, enhanced university and education curricula, as well as supporting and improving green innovations and entrepreneurship by making it easier to create green businesses—with incubation services—will ensure a just transition.

A well-managed approach to the transition to a decarbonized economy is necessary to avoid or minimize any adverse impacts to workers, communities, and businesses in regions that will be most affected by the transition. Engaging with the affected stakeholders and introducing policies for social protection, retraining, and reskilling are important enabling factors of a smooth and fair transition assuring prosperity for all Hungarians.

4.3.3. Linkages with the UN Sustainable Development Goals

Reducing GHG emissions generates a variety of co-benefits which can be identified by their contributions to the UN SDGs. First, the implementation of low-carbon investments (SDG13) leads to employment creation (SDG8) and the generation of new skills and knowledge (SDG4). In the case of the energy sector, these investments improve the expansion of clean and affordable energy (SDG7). Investments in energy and waste management also improve the creating of domestic value chains (SDG9). The result of low carbon investments is reduced energy use, waste creation and the increase of natural sink capacities which represent progress towards responsible production and consumption (SDG12) as well as towards sustainable cities and communities (SDG11). This also strengthens health outcomes (SDG3) via the reduction of air and water pollution (SDG6), by increased physical activity and better nutrition from interventions in the agriculture sector (SDG2).

4.4. Adaptation policies and measures

Adaptation to the unavoidable impacts of climate change is as important as emission reduction efforts for Hungary. Long-term adaptation priorities should be laid out jointly with the mitigation planning in order to fully seize the opportunities of the synergies between the two areas.[32] This joint planning is also important because the necessary investments for adaptation determine development. Furthermore, adaptation activities contribute to important socio-economic goals and can bring added mitigation benefits. This applies vice versa since mitigation measures can have added adaptation benefits as well. This aspect has been taken into account during the preparation of the NCDS. In addition, those mitigation policy recommendations that are contradictory i with adaptation objectives should only be considered as a last resort.

[32] A good example for this is the revision of requirements related to the planning of renewable energy facilities in the power sector that foster mitigation taking weather conditions impacted by climate change into account that risk critical infrastructures.

4.4.1. Adaptation-related climate policy planning

The EU Adaptation Strategy[33] set three main goals for its member states:

- to support member state-level interventions, especially the preparation of national and municipal climate strategies;
- to strengthen the information database of decision-making, and
- to integrate the adaptation goals in the most affected sectors.

Hungary, fulfilling these requirements, accepted the National Adaptation Strategy (NAS) in 2018 with 6 specific goals that guide adaptation policy planning:

1) the protection of natural resources;

2) the adaptation of vulnerable regions;

3) the adaptation of vulnerable sectors;

4) the adaptation of policies areas with national strategic importance;

5) the adaptation of society; and

6) the strenghtening of activities that target related research, development and innovation.

The NAS outlines the concrete directions at short-, mid- and long-term for those Hungarian sectors that are mostly affected by climate change impacts. The implementation of the NAS is supported by actions plans that cover periods for 3 years each.

In January 2020, the Hungarian Government adopted the Report on the scientific assessment of the possible effects of climate change on the Carpathian Basin[34]. This also summarizes the most important challenges in the field of adaptation based on the most recent scientific literature available.

4.4.2. Potential response measures and interventions

In the case of **water management**, the problems related to water scarcity and water surplus need to be addressed, as well as flood defenses and the prevention of floods and flashfloods caused by torrential rain. In order to moderate the severity of water scarcity, it is essential to keep the natural precipitation in place at all areas (farmers, population, settlements). In regularly flooded areas, it may be necessary to review land use and to plan flood control and land use integratedly. An important tool for adaptation is the storage of natural precipitation in the ground, as well as the expansion of water-saving irrigation methods.

Climate change-related damage to **agriculture** is strongly linked to water management because an increase in the tendency to drought may pose the greatest risk to agriculture in the future. Hence, it is particularly important to develop land use - and a system of incentives for change - that will help reduce extreme weather impacts and ensure that soil fertility is maintained in the long term. Dissemination of natural water replenishment and conservation-friendly irrigation systems is key. Adaptive soil management, water management and the cultivation of plants suitable for the landscape can be used to prevent soil isolation and soil acidification.

[33] EU Commission (2013). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: An EU Strategy on Adaptation to Climate Change Brussels, 16.4.2013 COM (2013) 216 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0216&from=EN

[34] MIT (2020). Report on the scientific assessment of the possible effects of climate change on the Carpathian Basin. Available at: shorturl.at/dpzEM

Forests also play a prominent role in carbon sequestration and adaptation. It is therefore important to increase forested areas, depending on the conditions of production that change as a result of climate change, by using mainly native tree species that meet the changing conditions of production.

Preserving **natural and close to natural ecosystems** and restoring degraded ecosystems will help adapt to the effects of climate change. This requires the mapping of ecosystem services and the coordinated development of elements of “green infrastructure”.

In order **to prevent the harmful effects of climate change on human health**, it is necessary to prepare both the institutional system and its employees, as well as the population, for the intensifying effects of climate change and the possibilities of protection. It is necessary to compile action plans at the institutional and municipal level as well, and to create the possibility of cooling in institutions taking care of vulnerable groups (eg hospitals, social institutions). It is important to control the prevalence of animal carriers and to monitor infection data. Preparing for climate change emergencies and rapid public health responses is of key importance.

Municipalities have a wide range of options for preventing and managing the climate impacts that affect them. It is recommended to continue and further encourage the development of adaptation strategies with a focus on adaptation at the settlement and community level, which has started in recent years, together with the related local awareness-raising activities. It is essential that adaptation and sustainability aspects are consistently integrated and reflected in agglomeration, settlement development and town planning. Furthermore, in the construction sector, adaptation and sustainability aspects need to be consistently incorporated and presented in the strategic and planning documents as well as construction and land-use rules have to reviewed, tightened and enforced taking climate change into account. A detailed review of the design and construction conditions of the municipal green space system, as well as the system of rules concerning elimination and felling, is also essential. Registering, planned expansion and quality development of green spaces to improve adaptability and strengthen absorption capacities locally is a key task. The safe collection, retention and utilization of precipitation requires the climate-safe removal or conversion of municipal stormwater management systems. Investigation of the storm damage vulnerability of the municipal building stock and damage risk analysis can also help to prepare for and develop effective, innovative responses.

The adaptation of the **transport sector** can be interpreted from the infrastructure and from its users’ perspective. An important task is to prepare the transport infrastructure for extreme weather events (heat waves, storms, extreme precipitation), by developing related action plans and specific interventions (e.g. the use of more heat-resistant pavements). During transport developments, alternative, environmentally friendly, sustainable (eg fixed-track) modes of transport are preferred.

In addition to being one of the largest emitters, the energy sector is also a affected in adaptation. In the future, in line with changing weather elements and trends, it is necessary to consistently integrate the consideration of climate risks into power plant and energy (gas, electricity and district heating) infrastructure planning. The development of a climate risk assessment methodology that takes into account the actual chains of impact is key to the “climate security” of the energy production and distribution network. The reserves of weather-dependent renewable energy sources and their sustainable utilization possibilities need to be reviewed in view of the expected climate change, revealing domestic potentials (e.g. the use of geothermal energy as a weather-independent renewable energy source).

Besides **avoiding preventing and preparing for disasters**, it is also an important task to mitigate **the already occured damages**. A key goal is to develop defense and forecasting systems together with neighboring countries, and to coordinate action. Preparing for the potential municipal consequences arising from climate risks is also a task at the level of local governments in the field of food safety, flood risk and drinking water protection as well as critical infrastructure protection and industrial safety. At the municipal level, a further task is to assess the areas sensitive to surface movements, to review the existing landfills, slurry and sludge reservoirs and tailings ponds, as well as the areas potentially designated for landfill.

In the **tourism sector**, the two main trends are to strengthen and disseminate adaptation knowledge bases and to encourage local responses. Within the framework of the former pillar, the central methodology development can take place in order to develop destination risk analyzes and vulnerability studies. The elaboration of related destination-level practice-oriented climate risk assessment and the development of guidelines, aids, manuals, related training, event organization and curriculum development in support of strategic planning in the field of tourism also support these trends. In the field of tourism, the climate-conscious approach is gaining more ground due to the climate awareness of the actors of the sector regarding the effects and consequences of climate change. Another important group of concrete local responses in attraction development is product diversification, the promotion of indoor products in the host area and the promotion of domestic tourism as well as the application of energy and water saving investments and product development adapted to climate effects in general.

4.5. Cross cutting policies

The entire system of public organizations, the society and all sectors of the economy must play their part in the fight against climate change. Sectors that play a key role in reducing GHG emissions and increasing GHG sequestration (Chapter 4), as well as enabling funding (Chapter 5) and supporting RDI (Chapter 6), are discussed in separate parts of this strategy. However, it is also necessary to talk about those cross-cutting areas that cannot be clearly classified into the examined sectors, which significantly facilitate the effective transition to climate neutrality. These are areas that can have a positive impact on processes in all emitting and absorbing sectors. The Preamble to the Paris Agreement also highlights cross-cutting issues that are crucial for the effective implementation. These are:

- education and training,
- public access to information, social consciousness,
- full participation and cooperation of all levels of government and stakeholders,
- sustainable lifestyles and sustainable consumption and production patterns.

4.5.1. Education and training

Article 12 of the Paris Agreement prescribes that "The Parties shall cooperate, as appropriate, in promoting measures to support education and training on climate change, recognizing the importance of these steps in enhancing actions set out in this Agreement." The Paris Agreement reaffirms the key role of education and training. As discussed in the NCCS-2, it is of particular importance to shape attitudes through education in which sustainability issues are presented in an integrated way, not in isolation. Knowledge that draws attention and teaches consciousness about sustainable development needs to be incorporated into curricula.

With a commitment to the environment, the professionals of the future need to implement ideas that take the impact of their activities on the environment into account.

In primary and secondary education, the National Core Curriculum (NAT)[35] **already reflects these important aspects.** Between the first and eighth grade, the main topics include "preserving the order of nature for sustainability". Among the learning outcomes, the aspects of sustainability appear in a specifically practice-oriented way.[36] The NAT also sets additional sustainability requirements for more senior years.[37] There is also a non-governmental organization in Hungary to promote the above goals. [38]

The same approach is needed in higher education, where it is necessary to transfer comprehensive and special knowledge related to sustainability and climate change, adapted to the needs and aspects of each specialization. In these areas of higher education (e.g. medical training, disaster management, economics, engineering, law training, etc.) understanding climate change and global environmental issues is particularly important, especially for the effective climate-neutral transition and preparedness for the unavoidable impacts. The (re)training of professionals competent to develop and/or apply new technologies and processes is key to achieving climate neutrality goals. Therefore, the identification of relevant areas of higher education and other vocational training and the appropriate transformation of training is a key policy objective. Last but not least, support for research relevant to the fight against climate change in post-graduate and doctoral programs should be promoted.

4.5.2. Public participation, public access to information and social consciousness

In addition to education and training, there is also a need to increase the general awareness of the society. Article 12 of the Paris Agreement prescribes that "The Parties shall cooperate, as appropriate, in supporting measures to promote [...] public awareness of climate change, public participation and public access to information, recognizing the importance of these steps with respect to enhancing the actions set out in the Agreement. " Therefore, in addition to the Preamble, the Agreement confirms the key role of these areas in a separate operational provision as well.

Hungary is a party to the Aarhus Convention[39], which also legally guarantees the "right of the public to have access to information, to participate in decision-making and to access justice in

[35] Government of Hungary (2020). 5/2020. (I. 31.) Government Act modifying Act 110/2012. (VI. 4.) on issuing and implementing the National Core Curriculum. Available at: https://magyarkozlony.hu/dokumentumok/3288b6548a740b9c8daf918a399a0bed1985db0f/megtekintes

[36] E.g. sets an example in toy purchasing habits of elements that can be used to take environmental considerations into account, and also draws the attention of its peers to these; in the selection of packaging used on a daily basis, it justifies the application of the principles that promote environmental considerations and draws the attention of its peers to them, etc.

[37] E.g. it interprets the local and biosphere consequences of global climate change on wildlife based on research data and forecasts; analyzes the causes and consequences of air, water and soil pollution, industrial and natural disasters, the impact of human activities on habitat change on the basis of examples, explains the endangerment of certain species, etc.

[38] The aim of the Hungarian Environmental Education Association is to develop environmental education, to support learning sustainability, and to help the work of those involved in environmental education and to represent their interests. Available at: http://www.mkne.hu/index.php

[39] EU Commission (2001). Law LXXXI. (2001) promulgating the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, adopted in Aarhus on 25 June 1998. Available at: https://net.jogtar.hu/jogszabaly?docid=a0100081.tv

environmental matters".[40] This has a special role in the climate-neutral economic and social transition in all aspects. First and foremost, society needs to be informed about the most up-to-date scientifically based information available on possible global and local environmental problems, challenges and solutions. The collection and wide distribution of these data, tailored to the needs of the target audience, should be facilitated by the state. Only a well-informed society can be expected to make conscious decisions and take environmental considerations into account than before. This process will also strengthen social support for action on climate change by providing rational and publicly sound arguments in support of, inter alia, the proposals set out in this strategy.

NCCS-2 deals with the main directions of action on climate awareness and partnership in a separate chapter. These include horizontal integration, the implementation of NCCS-2 in public administration and partnerships with the media and churches as well as complex campaigns for climate awareness and network building with the involvement of governmental, economic, civil, scientific and church actors. These, as well as the activities described in Chapter 7 of the NCDS, all contribute to the complex process of information transfer and sharing. In addition to the above, the tasks to be performed separately by the state in order to achieve the above goals are:

- Preparing or supporting the preparation of reports and other awareness-raising documents on climate change or other environmental issues and making them as widely available as possible to the public,
- Providing "one-stop-shop" information services for green economic transition programs or other measures initiated by the Government or other state bodies, involving the public and a wide range economic actor,
- Initiating, continuing and promoting information campaigns, events, dedicated days on environmental issues that can reach the general public as well as establishing restrictive regulations on information intended for public disclosure that is unsustainable or otherwise harmful to the environment,
- Establishing and maintaining partnerships, in particular with non-state actors and other non-governmental organizations, as well as churches, in order to communicate information more effectively,
- Priority support for local information sharing and awareness raising initiatives,
- Using most communication channels, including state-of-the-art forms of communication, capable of conveying short, creative, easy-to-understand messages, involving highly publicly recognized, credible actors who can easily reach large masses.

4.5.3. Full participation and cooperation of all levels of government and stakeholders

The climate-neutral transition requires the active participation and constructive cooperation of all actors. For the vast majority of the Hungarian society, climate change is a significant issue. A good example of this is that more than two hundred thousand people completed the questionnaire related the NCDS published by the Government in November 2019.[41] A

[40] Article 1 of the Aarhus Convention
[41] For more information, visit: https://2015-2019.kormany.hu/hu/innovacios-es-technologiai-miniszterium/energiaugyekert-es-klimapolitikaert-felelos-allamtitkar/hirek/a-kormany-klimapolitikajat-

recently published study showed that the Hungarian society is particularly concerned about the security consequences of climate change.[42] This concern should be translated into positive action, in which the state has a key initiating and organizing role. The forums in Chapter 7, organized by the current government, provide a permanent platform for consultation between a wide variety of groups.

4.5.4. Sustainable lifestyles and sustainable consumptions and production patterns

From the climate-neutral transition perspective, there are huge reserves in the production or other business policy decisions made by individual members of the society and economic actors. With the current energy-intensive and often wasteful way of life and production, a climate-neutral operation is not, or it is much more difficult and costly to achieve and maintain. Mass demand for consciously sustainable products and services is driving supply in this direction. Vice versa, a “green” favorable supply creates demand for more environmentally sustainable products and services. Therefore, supporting and promoting both is a priority.

Changing current lifestyles in a more favorable direction, and only developing behaviors that seek to meet our needs, is the biggest contribution to the fight against climate change that individuals can make. The greenest energy is the unused energy. At the same time, a supportive regulatory environment that promotes and provides incentives for more sustainable lifestyles and production is essential for well-informed decisions by individuals and economic actors.

5. Financing Climate Neutral Transition and its Economic Policy Instruments

Vision: "The flow of financial resources is in line with the financing needs of domestic green and climate action investments."[43]

Adequate financing of the climate-neutral transition is critical in tackling global climate change. This is confirmed by Article 2 (1) (c) of the Paris Agreement, which states that one of the main objectives of the Agreement is to make “finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.” Based on the EA scenario, which generates several benefits in the long run, the climate neutral transformation of the Hungarian national economy would require about HUF 23.8 billion, which assumes the involvement of resources equivalent to 4.8% of GDP per year by 2050. In order to make this amount available from public and private sources, this long-term concept proposes appropriate funding instruments and mechanisms.

Some of the presented proposals have been included in this chapter of the Strategy after consultation with representatives of the financial market and other financial organizations[44]. Investments aimed at reducing CO_2 emissions are capital-intensive, so it is justified to

tamogatjak-a-valaszadok-es-az-ev-vegeig-kidolgozza-a-tarca-a-klimasemlegesseg-2050-es-eleresehez-szukseges-strategiat

[42] Etl, Alex. (2020). The perception of security in Hungary, Institute for Strategic and Defense Studies ISDS Analyses 2020/3. Available at: https://svkk.uni-nke.hu/document/svkk-uni-nke-hu-1506332684763/ISDS_Analyses_2020_3_The%20perception%20of%20security%20in%20Hungary_(Alex%20Etl)%20(1).pdf

[43] UNFCCC (2016). Pursuant to Article 2 (1) (c) of the Paris Agreement. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:22016A1019(01)&from=EN

[44] “Climate breakfast” consultation with representatives of the financial sector: 16 June 2020.

increase the bankability of investments with loans and state subsidies (e.g. repayable subsidies, interest rate subsidies, loan guarantees). The financial conditions for a climate-neutral transition must be created jointly by the **private and public** sectors, as investment depends not only on banks' willingness to finance, but also on a stable, transparent and predictable political and economic environment.

Several proposals have addressed the importance and role of **green bond issuance** as an effective tool for dedicated fundraising. Mainstreaming **environmental, social, and governance (ESG)** principles, promoting a **green mortgage market,** applying the **EU sustainable investment taxonomy**, **energy efficiency requirements** and green bonds all have a positive impact on the development of green projects and interventions. The Strategy took into account the proposals for the establishment of a state green guarantee institution, which would strengthen the market balance by reducing the competitive advantage of unsustainable investments. Stakeholders also support the spread of Energy Services Companies (ESCO)-type bank financing in the context of municipalities and companies.

The detailed development and follow-up of these proposals is the responsibility of the Green Finance Working Group comprising of key public, banking and other financial market actors, presented in Chapter 7.

5.1. Transforming economic policy for a climate neutral transition

In addition to the development of the domestic capital market and the financial sector in general, the climate-neutral transition requires a governmental economic policy that promotes low-carbon growth. Each of the individual economic and regulatory functions of the state can contribute to this, with sustainability in mind, as follows.

Through the "greening" of its **allocation function**, the state ensures the full use of resources among private and social goods by enforcing environmental and sustainability considerations in the process. This means preventing social and environmental harm caused by market failures through fiscal policy in such a way that a healthy environment, energy and resource efficiency become an important part of social goods, i.e. the process of allocating resources is also influenced by green criteria.

The aim of "greening" the **redistribution function** is to motivate income redistribution not only to alleviate income inequalities but also to reduce negative environmental impacts. The reform of the taxation system and public transfers should be done in a way that supports environmentally sustainable consumption and technological innovation, while over-consumption and environmentally harmful activities are sanctioned by additional taxes.

The "green" **stabilization function** aims to smooth out fluctuations in employment, inflation and GDP in order to promote clean and green economic development. Through this function, the state can direct labor force towards green and clean jobs, support domestic companies developing high value-added, innovative clean technologies and services, i.e. respond to the economic challenges arising from phasing out carbon and the green transition, while using the inherent economic potential of the process.

By "greening" the **regulatory function** of the state, it shapes fiscal policy and the regulation of the money, capital and insurance markets in such a way that climate protection and environmental sustainability are given a prominent role, among other fiscal aspects.

In addition, climate-friendly fiscal and economic policies have the overall task of creating a growth-friendly environment that supports the development and innovation of clean technologies and generates social, environmental and economic benefits. It is also important that this supportive environment also helps to take advantage of new business and foreign trade opportunities arising from technological developments in order to create high-quality, sustainable jobs and increase the competitiveness of companies.

5.1.1 Climate friendly budget planning

Climate-friendly, green fiscal policy is an essential tool for achieving environmental and climate goals.[45] Green budgeting aims to align the country's expenditures and revenues with climate and other environmental goals. This requires designing both the revenue and expenditure side from a different perspective. On the revenue side, the taxation system is a crucial budgetary tool for "correcting" the prices of activities that generate negative externalities, such as CO_2 emissions and pollution. An important aspect is that green budget planning builds on the country's existing public finance management framework and thus aligns with the strengths and constraints of existing fiscal processes.

Effective green budgeting consists of four mutually reinforcing key components[46]:

1) **Strong strategic framework**: the Government aligns the objectives of environmental and climate strategies with decisions on tax policy (e.g., green taxation), state aid (phase out of fossil fuel subsidies) and public spending (e.g., green public procurement).

2) **Tools for justification and coherence of green budget measures/decisions:** Green budget tools provide evidence of how certain budget measures/decisions affect environmental and climate goals. These tools can be:

a) Green budget labeling[47]: classification of budgetary measures according to their environmental and/or climate impact.
b) Environmental impact assessment: carry out environmental impact assessments for new budgetary measures.
c) Ecosystems valuation and pricing of environmental externalities, such as the price of greenhouse gas emissions, through taxes and emissions trading schemes.
d) Green review of expenditure: taking into account the impact of expenditure on environmental and climate objectives.
e) Green performance requirements: aligning budgetary performance requirements targets with environmental and climate objectives.

3) **Green reporting for accountability and transparency**: The Government submits a green budget report accompanying the annual budget to the Parliament, which provides a comprehensive picture of how the budget is aligned with the green objectives in the given budget year.

4) **Governance and implementation of green budgeting**: The implementation of green budgeting is based on strong political leadership, clearly defined roles and responsibilities within the government, a well-designed sequence of implementation, appropriate internal systems, and continuous improvement of the skills and expertise of government officials.

[45] OECD (2020). Paris Collaborative on Green Budgeting. 20 October 2020. Available at: https://www.oecd.org/environment/green-budgeting/
[46] OECD (2020). OECD Green Budgeting Framework. Available at: https://www.oecd.org/environment/green-budgeting/OECD-Green-Budgeting-Framework-Highlights.pdf
[47] In accordance with the Taxonomy Regulation 2020/852.

5.2. Financial and investment needs of climate neutrality

As revealed in Chapter 4, achieving a climate-neutral transition by 2050 will require a total of approximately **HUF 24.7 billion** in additional investment in all emitting sectors compared to the BAU scenario, which will require the mobilization of resources equivalent to **4.8% of GDP** per year until the target date. It is important to note, however, that mobilizing this huge amount should not only burden Hungary's national budget, but also - as discussed in this subchapter - give priority to the involvement of financial and capital markets, EU funds and blended financing of public and private funds. This is because market-based and blended financing allows limited taxpayer resources to be used for leverage to mobilize 10 or even 20 times of the amount being invested.

The costs of investments to be made over the period up to 2050 are distributed between the sectors as follows:

- Decarbonization of the energy sector, including the energy efficiency modernization of buildings, improvement of electricity infrastructure, increase the efficiency in the service sector and electrification of the transport sector: **HUF 22.4 billion**
- Investments related to the reduction of emissions from agriculture, including animal husbandry, crop production and soil cultivation: **HUF 745 billion**
- Development of the waste management sector and promotion of the circular economy: **HUF 480 billion**
- Modernization of industrial production processes, increase of production efficiency: **HUF 129 billion**
- Increasing the CO_2 sequestration capacity of the LULUCF sector: **HUF 964 billion.**

Table 11 also provides information on how investment costs will change over the period of 2020-2030.

5.3. The role of the financial sector in the green transition

In the double grip of the health and financial crisis caused by the COVID-19 pandemic, the transition to a green economy opens up new types of investment opportunities, but also imposes financing needs comparable to the post-World War II reconstruction[48]. The role and importance of the financial sector is shown by the fact that it would not be impossible to finance this investment need from public funds only, given the budgetary constraints of national economies. Thus, it is absolutely necessary for the private sector, and especially financial institutions, to channel more capital towards green developments and investments than at present.

5.3.1. The need to develop domestic financial markets[49]

Based on international experience, there is a huge potential for mobilizing capital markets, especially because the typically longer maturity of capital market instruments fits well with

[48] Claudia Kemfert, Dorothea Schäfer, Willi Semmler. (2020). Great Green Transition and Finance. Intereconomics. Available at: https://www.intereconomics.eu/contents/year/2020/number/3/article/great-green-transition-and-finance.html

[49] Laura Jókuthy, Nóra Szarvas and Gábor Gyura. (2020). Recommendations of the Central Bank of Hungary for the National Clean Development Strategy. July 2020. Budapest.

the typically longer payback period of green investments. That is why the NCDS's funding pillar consists of a strong capital market package as follows:

a) Development of a *National Sustainable Capital Market Strategy*: Within the framework of the European Union Structural Reform Support Service and with the participation of the European Bank for Reconstruction and Development (EBRD) and the Central Bank of Hungary (CBH), investment service providers, investors and other market participants, ministries and all other relevant stakeholders a project promoting the "greening" of the domestic capital market was launched in Hungary. The aim of the comprehensive initiative is to enable the capital market to finance investments in environmental sustainability to a greater extent than at present, and for "green" companies to have access to more favorable capital or bond-type resources.

b) *Green bonds*: In June 2020, the Hungarian government issued first green government securities worth EUR 1.5 billion in the European market and then JPY 20 billion in the Japanese market, raising dedicated funds for government investments related to Hungary's climate and environmental goals. The aim is to support the start-up of domestic corporate, bank or even municipal green bond issuances – in accordance with Act CXCIV of 2011 on the economic stability of Hungary - and the strengthening of venture capital to finance climate-friendly innovations, accompanied by various regulatory incentives.

c) *Green investment and venture capital funds, "greening" of fund portfolios*: At present, investment funds and funds with domestic sustainability themes can essentially only buy foreign green assets into their portfolios, and thus retail green investments also flow abroad. The emergence of domestic green bonds and the development of the ESG rating of listed companies could change this situation in such a way that it also contributes to the development of investment funds. It is a positive trend that domestic fund managers have moved towards ESG-based portfolio management practices[50]. Strengthening venture capital is also a goal to finance climate-friendly innovations.

d) *Sustainable Stock Exchange*: The Budapest Stock Exchange joined the Association of Sustainable Stock Exchanges in 2019 and is committed to encourage stock market issuers towards sustainability. If the climate and other environmental performance data of large domestic listed companies become more transparent, then the green assessment of companies will also become possible, thus further helping the desired green capital flow. The Sustainable Exchange Initiative, in collaboration with investors, regulators and companies, can improve sustainability and ESG considerations for investments.

5.3.2. Financing instruments in specific sectors

a) Support for energy efficiency modernization of residential buildings

Promoting the energy efficiency renovation of residential buildings is a national economic interest, given that this type of investment has not only one of the greatest GHG saving potential (see Chapter 4.), but is also capable of creating large number of jobs on a

[50] Central Bank of Hungary (2020). The central bank welcomes BAMOSZ's initiative on ESG investment funds. October 13, 2020, Available at: https://www.mnb.hu/sajtoszoba/sajtokozlemenyek/2020-evi-sajtokozlemenyek/a-jegybank-udvozli-a-bamosz-kezdemenyezeset-az-esg-befektetesi-alapokrol

lasting basis. In addition, they provide significant health benefits.[51] Building on the experience of previous energy efficiency loan schemes, the aim is to develop a comprehensive state support system (repayable grants, interest rate subsidies and loan guarantees) based on the competitive and flexible framework of commercial banks. Therefore, a joint "package" of several measures is needed to ensure adequate funding sources as follows: (1) CBH announced a capital requirement discount for green housing loans, thus increasing banks' interest in such loans[52]; (2) this measure should be complemented by a comprehensive support structure mobilizing private resources (such as repayable, non-repayable grants and interest rate subsidies) for renovation loans, and (3) the introduction of a loan guarantee scheme to reduce credit risks.

b) Launch of the green mortgage bond market

Green mortgage bonds are a targeted source of funding for banks to finance the construction and purchase of energy-efficient properties through loans, thus contributing to the energy modernization of the building stock. In the case of green mortgage bonds, the issuer undertakes to have at least the same amount of green mortgage loan in the loan portfolio as the collateral for the mortgage bonds during the term of the bond. This may encourage lenders to prefer such mortgages, which may even lead up to more favorable interest rates. To date, banks in five European countries (Germany, Norway, Sweden, Denmark and Poland) have issued green mortgage bonds.

c) Support for other energy efficiency investments, introduction of the energy efficiency obligation scheme

Hungary will ensure the cost-effective implementation of the goals undertaken in the field of energy savings and energy efficiency by introducing an **energy efficiency obligation scheme**. The scheme will include a number of measures to encourage energy efficiency renovation. The obligors are service providers engaged in the retail sale of gas, electricity and motor fuels, commercial enterprises, universal service providers of gas and electricity. Under the scheme, obligors implement interventions that result in energy savings for end users. This can be done in a number of ways: through investments in energy efficiency or through contributions.

For the period from 1 January 2021 to 31 December 2030, each year, new savings of 0.8% of annual final energy consumption must be achieved over the average of the last three years preceding 1 January 2019.

d) Support for renewable energy production

On 1 January 2017, the **system for the support of electricity produced from renewable energy sources (METÁR)** came into force. In the METÁR system, support for new investments can currently only be applied for in the form of a green premium-type entitlement awarded within the framework of a tender procedure. In the tenders, the producers compete on the basis of their bids for the subsidized price, for a subsidy amounting

[51] Diana Ürge-Vorsatz, Radhika Khosla, Rob Bernhardt, Yi Chieh Chan, David Vérez, Shan Hu, Luisa F. Cabeza. (2020). Advances Toward a Net-Zero Global Building Sector. 2020 45:1, 227-269. Available at: https://doi.org/10.1146/annurev-environ-012420- 045843

[52] Central Bank of Hungary (2019). The central bank introduces a capital requirement discount program for green housing purposes. 16 Dec 2019. Available at: https://www.mnb.hu/sajtoszoba/sajtokozlemenyek/2019-evi-sajtokozlemenyek/lakascelu-zold-tokekovetelmeny-kedvezmeny-programot-vezet-be-az-mnb

to HUF 2.5 billion per year. In the premium system, the producer sells the electricity and receives the subsidy above the market reference price.

According to the Government's plans, following the two tenders so far, a total of four new METÁR tenders are expected to be announced by August 2022. According to the plans, new calls will be issued by the Hungarian Energy and Public Utility Regulatory Authority (MEKH) every six months, to support the production of renewable energy between 300-500 GWh per year per tender. In order to boost investments, the aim is to facilitate METÁR's bank financing with support measures that (i) reduce interest rate and exchange rate risk (e.g., subsidized, fixed-rate credit facilities, subsidized interest rate/hedging framework), or (ii) reduce credit risks and refinancing risks (e.g., with the loan guarantee institution) and thereby easing expectations regarding funding maturity and debt service ratios.

e) Launch of municipality level green funding

The borrowing of municipalities is currently subject to an ad hoc government permit in accordance with Act CXCIV of 2011 on the Economic Stability of Hungary. In compliance with the law, numerous municipal green development projects (development of public transport, waste management, water management, renovation of municipal buildings, renewable energy production, etc.) that provide a well-calculated return may be possible with a **municipal green loan program** and green bond issuance, following the creation of a legal environment conducive to financing.

f) Launch of the domestic voluntary carbon offset market

Carbon markets offer a cost-effective opportunity to reduce emissions. The voluntary carbon market is gaining ground, focusing on synergies with financial and capital markets: for example, some banks are actively supporting their own carbon-offsetting customers to sell their capacities to GHG emitting companies. Large companies outside the EU ETS may become increasingly interested in offsetting their own GHG emissions, even without a specific regulatory obligation or incentive. However, ensuring market integrity requires the involvement of reliable carbon credit rating agencies and/or government involvement in credit validation.

Sector	Areas of intervention	Proposals and interventions to be examined
Energy	*Energy efficiency of residential buildings*	• Providing capital requirement discount for credit institutions for green housing loans • Providing complex support programs that mobilize private sector sources (such as grants and interest rate subsidies) • Introducing a loan guarantee program to reduce credit risk expectations • Launching a market for green mortgage bonds
	Other energy efficiency investments, energy efficiency obligation scheme	• Supporting the spread of ESCO-type financing. Possible combined financing structures are included in the framework of the Energy Efficiency Obligation Scheme under development. • Reducing the cost of capital and the risk premium in the case of ESCO schemes by extending CBH's green capital requirement discount. • Reduction the cost of capital and the risk premium through state-subsidized programs • Reducing the cost of capital and the risk premium in the

		case of "normal" bank loans with a guarantee institution (e.g., in the case of universal consumers/consumer portfolios with weaker financial strength). • In connection with energy efficiency financing, supporting and encouraging basically market-based lending with fiscal concessions (e.g., from EU funds).
	Renewable energy production	• *Strengthening capital market financing*: increase the supply side of renewable energy sources by strengthening capital market financing. In addition to the securitization of bank loans and the issuance of green bonds, the goal is to introduce and launch renewable investment funds in order to provide Hungarian energy retail savers and companies with a predictable and climate-conscious investment opportunity. • Supporting bank lending: examining development opportunities in areas such as credit, exchange rate and interest rate risk, cost of funds, collateral, rating models, as well as new forms of financing and construction. • Introducing of innovative solutions: There are many innovative solutions abroad in the field of financing renewable energy generation, several of which are relevant and applicable in Hungary: roof leasing can be mentioned as an example. In this construction, the properly oriented, parametric roof surfaces are leased by the company installing the solar panels and the energy produced in addition to satisfying the energy consumption of the building is sold. • Energy community: Local energy communities are a specific form of aggregation based on renewable energy production. They help to ensure that the energy produced can be used locally (e.g., within a transformer area) and that fluctuations in production do not burden the distribution network.
Transport	*Urban public transport development*	• To be examined how to mobilize private resources for urban and suburban public transport developments. This includes an examination of targeted municipal green bond issuance, taxing land value gains, and special bank loans.
Agriculture		• To be examined: the sustainability of Hungarian agricultural and food enterprises, the incentives and motivations needed to become sustainable, the types of sustainability investments, the factors influencing the financing decision, the special financing needs and the relationship between the current credit supply system, compliance with EU taxonomy regulations on sustainable investments, reporting and the area of agricultural damage mitigation and insurance.
Circular economy		• To be examined: what incentives can be introduced to facilitate the financing of circular economic forms, solutions and implementations, and to monitor and verify the complex effects

Others	*Launch of municipal green funding*	• It is examined how it is possible for municipalities to borrow and/or issue green bonds to finance green investments in accordance with the financial stability act[53].
	Launch of the domestic voluntary carbon offset market	• Encouraging companies outside the scope of ETS to offset their emissions in the country of emission, i.e. in Hungary, even if it is more expensive than carbon credits available on international markets.

Table 12 – Sectoral and specific green financing recommendations and interventions to assess

5.3.3. Climate-neutral transition as a mean of attracting foreign investment

Attracting foreign direct investment (FDI) is a top priority for the Hungarian Government, especially in the field of green industry investments. The Hungarian Investment Promotion Agency (HIPA) was established in 2017 with the aim of providing professional assistance to foreigners wishing to invest in Hungary. Renewable energy and e-mobility are high on the list of investments to attract.

The adopted Climate Protection Act and the clear and ambitious target system set by the NCDS, including anchoring incentives for low-emission technologies in all sectors, show a strong commitment to a climate-neutral transition, which is an important attraction factor for green FDI. Apart from that, the additional financial incentives envisaged in this strategy (tax breaks, low-interest loans, etc.) have been shown to provide additional incentives for green FDI and thus create local jobs, which would also contribute to significant knowledge transfer.

Hungary has one of the highest share of exports related to high-tech industries in the Central and Eastern European region within all exports (OECD). This provides an excellent opportunity for taking a similar position in the green industry, using this experience and network. In Hungary, a highly skilled and competitive workforce is a great precondition for realizing high-tech renewable energy or other clean technology investments.

5.4. Possible sources and means of financing the green transition

The Hungarian financial and capital market is already lending activities that serve Hungary's climate and other sustainability goals - primarily in the field of renewable energy production. According to a report[54] of the Hungarian Banking Association, in 2020 the average maturity of climate-related lending was 13 years, the average equity requirement was 28%, while the loan portfolio amounted to HUF 172 billion and the additional market demand amounted to another HUF 150 billion. It is important to note that market-based lending is essentially driven solely by the risk-adjusted expected return on funding and the associated capital and operating costs. That is, green lending is currently done on an ad-hoc basis, “brown” (not serving environmental sustainability) investments receive financing with a similar chance and condition as green projects. In the case of non-refundable state support and funds, the conditions based on the green approach are also rare or soft, with the exception of dedicated programs (such as energy efficiency tenders).

[53] Government of Hungary (2011). 2011 CXCIV. Act on the Economic Stability of Hungary. Available at: https://net.jogtar.hu/jogszabaly?docid=A1100194.TV

[54] Hungarian Banking Association (2020). Report for the Ministry for Innovation and Technology. 30 June 2020. Budapest

The long-term success of decarbonisation may depend on the ability to channel capital towards green projects through appropriate measures. It must therefore be ensured that investments for environmental sustainability and environmentally sustainable economic activities consistently face a more favorable financing environment than “non-green” and especially “brown” investments and activities. This desirable state can be achieved by combining monetary and fiscal policy instruments:

a) in its own regulatory competence, the CBH “directs” the financial sector in the green direction by calibrating prudential regulation, with recommendations and warnings, without endangering its main tasks specified in the Central Bank Act;

(b) the government encourages green financing of banks and capital market participants, as well as other market participants (companies, households, etc.), through various fiscal measures; and with the optimal combination of incentives and penalties, it influences the realization of the necessary investments in the transition on the demand side.

It is also important to emphasize that the financial, capital and insurance markets have orders of magnitude more resources available than national budgets or EU funds for green purposes.

5.4.1. Guarantee institutions to promote green financing[55]

Positive externalities resulting from building retrofitting are most often not taken into account by financial market participants, i.e. without state incentives, fewer socially optimal investments are made. The supply side can be ensured by a state guarantee or an interest rate subsidy to a level that can establish a proper market equilibrium. The establishment of a dedicated green guarantee institution will ensure a targeted, conscious expansion of green funding. The basic multiplier effect of the guarantee is also present here: a unit of guaranteed amount allows for a loan of 10 or even 20 times, which can be used to multiply the growth rate of green investments.

The importance of the guarantee institution continues to grow during the downturn caused by the COVID-19 pandemic; due to its countercyclical operation it is excellent for green economic stimulus, counterbalancing banks' risk-averse strategies and financing green investments of under-collateralised customers.

As the introduction of an energy efficiency obligation scheme is an important tool in the NCDS (in which ESCO-based financing can be a key), the relationship between ESCOs and the guarantee institution is as follows:

- Prospective public utility obligors of the obligation system are typically more creditworthy, have cheaper access to funding than their end-users, but at the same time operate with strained liquidity, so the planned cash flow is very important for them. As a result, end-user segments where payment delays and non-deliveries occur are not target markets for them. By preferring the “best” customers, energy efficiency investments are not realized in Hungary to the extent what the market potential would actually allow.
- The portfolio guarantee, which can also be applied to the ESCO scheme, provides an effective solution to this problem. Based on the default rate of the utilities' customers, the extent of the guarantee required by the guarantee institution for the entire portfolio can be calculated. For example, at a default rate of 5%, a portfolio loss guarantee calibrated on

[55] Laura Jókuthy, Nóra Szarvas and Gábor Gyura. (2020). Recommendations of the Central Bank of Hungary for the National Clean Development Strategy. July 2020. Budapest.

the basis of expected loss has a twenty-fold multiplier effect, while an energy efficiency investment in an ESCO scheme could be implemented for customers who would not otherwise have been selected by the obligor without a guarantee incentive. In addition to the general public, the end-user clientele also includes, for example, state-owned companies, educational institutions, local governments and hospitals.

- The portfolio-type guarantee can be used for loans financing the modernization of non-residential real estate, as well as for household-sized solar collector and PV investments, as well as for financing small-scale solar power plants, which are subject to individual, lengthy assessment by banks. Bank financing expertise is usually concentrated in project lending, however the financing needs of these clients do not reach the entry threshold for project lending.

The following advantages justify the consideration of setting up a **Green Guarantee Institution**:

- concentrates green industry expertise within one organization;
- supports the building of the historical experience of financiers (this could be helped by the creation of "green" pilot projects in all industries with the support of the guarantee institution);
- provides free technical and green advice on the investments to be made;
- provides guarantees not only for loans but even green bonds (by reducing the risk premium, the pricing of the funds covered by the green bond can be improved, which indirectly improves the return on the financed investments);
- It also encourages equity placements (such as support for green venture capital funds)

5.4.2 Available European Union funds

In the EU budget period **2021-2027**, Hungary is expected to receive a total of ~ EUR 42 billion (approximately HUF 14 -15 thousand billion) of EU funding from the 2021-2027 **multi-annual financial framework** and the **Next Generation EU** framework, which includes non-refundable and refundable forms of support, but does not include a mandatory minimum national co-financing. Of this, the **relevant budget for the implementation of this Strategy is EUR 30.88 billion** in the following composition (excluding Common Agriculture Policy support):

- Cohesion Fund support: EUR 21.73 billion,
- Non-repayable part of the Recovery Fund: EUR 7.17 billion,
- Just Transition Fund: EUR 0.25 billion,
- Estimated national share of EU direct programs: EUR 1.73 billion.

Of this, the minimum amount to be used for climate goals under EU regulations is expected to be EUR 8.2 billion. Together with the mandatory minimum national co-financing, HUF 2.9 billion is available to finance climate investments by 2030.

Part of the above is the newly established **Just Transition Mechanism**, which aims to support the economic transformation of regions' sectors that are affected by climate policy developments. Although negotiations are still ongoing, Hungary will receive a grant of EUR

294 million from the Just Transition Fund, which may be complemented by loans from Pillars 2 and 3 of the Just Transition Mechanism.

The framework available to Hungary presented above does not include the subsidies available under the Common Agricultural Policy, so the climate-related interventions to be implemented in the field of agriculture do not burden the HUF 4.1 billion envelope.

The framework, on the other hand, includes sources available from directly EU-managed programs, on the assumption that Hungary will be able to increase the amount of national support it has received over the period 2014-2020. Programs under direct EU management will be available to finance energy and climate protection projects with increased funding for the period 2021-2027, such as Horizon Europe (RDI), the Connecting Europe Facility (energy infrastructure), LIFE (environment, climate policy), Digital Europe (digitalization), InvestEU (efficient transport infrastructure, green energy and innovation) and the Innovation Fund (innovative carbon-free technologies, CCUS, innovative renewable energy production, energy storage).

In the third trading period of the EU Emissions Trading Scheme (2013-2020), a certain proportion of the revenues from the sale of allowances (50% of European Union Allowance (EUA) III unit sales, 100% of EUAA aviation unit sales) will be used in the appropriations managed by the Green Economy Financing Scheme. Between **2021 and 2030, assuming an average CO_2 price of EUR 25 per ton, a quota revenue of approximately HUF 910 billion**[56] **can be planned**. Of this, HUF 726 billion will be available according to the general rules of quota revenues[57], i.e. 50% (HUF 363 billion) will be used for green economy development purposes.

The part of the quota revenues for the development of the green economy is supplemented by the resources of the Modernization Fund[58] **in the amount of HUF 184 billion:** Hungary will be entitled to these in excess of the amounts used according to the general rules of current quota revenues. **The Modernization Fund, which has been in place since 2021**, **aims to modernize energy systems and increase energy efficiency**. At least 70% of the available financial resources must be used to support investments that meet the priority list of the Modernization Fund. For the remaining 30% of the funds, other projects related to the modernization of the energy system may be supported. For projects on the priority list, the aid intensity may not exceed 100%, otherwise up to 70%. The priority list that can be revised in 2024 includes the following elements:

- production and use of electricity from renewable sources;
- improving energy efficiency in all sectors;
- energy storage;
- modernization of energy networks, including district heating lines and electricity networks;
- expanding connections between Member States;

[56] The estimation of revenues is subject to considerable uncertainty, as the price of allowances is traded on the stock exchange and is also affected by the functioning of the market stability reserve, the need for free allocation and certain political factors (e.g., Brexit). Therefore, the figure can only be considered as an indicative estimate.

[57] Directive 2003/87 / EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61 / EC (Article 10 (3))

[58] Financing mechanism under Article 10d of Directive 2003/87 / EC of the European Parliament and of the Council.

- supporting just transition (human aspect).

The domestic application of **derogation 10c** between 2021 and 2030 is intended to replace electricity generation with high greenhouse gas emissions with natural gas or sustainable technologies. The aid intensity may not exceed 70%. The winning projects will be selected through a call for proposals.

In total, between **2021 and 2030, the amount of EU funds available to Hungary to finance the green transition and the achievement of climate goals may exceed HUF 3 500 billion.**

6. Research, Development and Innovation

Achieving climate neutrality requires a long-term reduction in GHG emissions and an increase in sink capacities at a rate which is currently not possible with existing technologies, or achievable at excessive costs, or only feasible with radical lifestyle changes that are disproportionate to the pursued goal. According to the International Energy Agency (IEA), nearly 45% of the emission reductions will be carried out by technologies that are currently in the development phase (characterized by the first four stages of the TRL scale[59] including basic and applied research phases). For that matter, RDI are crucial to achieving our energy and climate goals. Furthermore, the reduction in cost induced by RDI will significantly promote the expansion of new technologies.

6.1. Innovative technologies and solutions

In the future, the multiplication of mitigation and adaptation technologies will need to be promoted since only one technology or alternative fuel will not be enough to decarbonize our economy and adapt to the negative impacts of climate change. Therefore, the successful outcome depends on the availability of technologies and alternative fuels as well as on the right combination of the possible solutions.

6.1.1. Value chain maturity of critical energy technologies

According to the IEA, the full decarbonization depends primarily on the value chain maturity of electrification, hydrogen (and its derivatives), bioenergy as well as of CCUS technologies that ensure the capture, storage and utilization of CO_2. Therefore, the scaling up of currently available clean technologies as well as the emergence of new technologies and their market application should be supported.

Independent modelling results point out that achieving net zero emissions will bring along extensive **electrification**. According to the IEA, in order to reach global climate neutrality by 2050, electricity production should be increased about 2.5 times by mid-century. This demand should be covered by clean, carbon free (renewable and nuclear) sources. Based on the EA scenario, electricity production in Hungary will be around 3 times of the current level by 2050.

Achieving climate neutrality requires a radical change in the methods of energy supply, transformation and consumption. Furthermore, the integration of energy capacities is a key task which demands a smarter, more resilient and flexible electricity network that can adopt to necessary weather-dependent capacities.

It is essential to extend renewable energy sources as well as nuclear capacities to achieve the climate neutrality target. In the field of nuclear power, further efforts need to be made to reach the necessary levels.

Renewable energy generation fundamentally depends on the availability of renewable energy sources and the readiness of the electricity network. In Hungary, solar energy is the most potential source for renewable energy generation. In the field of photovoltaic technology, alongside other variable / weather-dependent renewable technologies, there has been a

[59] The maturity of technologies under development is characterized by Technology Readiness Levels (TRL). This method was developed by NASA originally identifying levels from 1-9. The IEA extended this scale to 11 levels that includes the most mature technologies in the list. Levels 1-4 characterize technologies in the preliminary phases of research and development (basic and applied research), while Levels 5-8 identify system models or prototype demonstration in a relevant operational environment. Level 9-10 stand for proved solutions and technologies ready for commercial deployment. Level 11 corresponds to the most mature technologies.

significant progress in the past decade. Many technologies have reached the level of early application and have become more cost efficient which contributes to the expansion of renewable energy capacities.

Renewable energies rapidly shape global energy production systems. According to data from the International Renewable Energy Agency (IRENA), renewable capacities accounted for 72% of the total new capacities in 2019. The price of electricity produced by renewable sources has dynamically decreased in the past decade due to technology developments, economies of scale and the increasingly competitive supply chains. Based on recent IRENA data, between 2010 and 2019, the levelized cost of energy (LCOE) for the operating time of utility-sized solar panels decreased by 82%. In the case of concentrated solar panels (CSP) it decreased by 47% in the same period.

Although, further innovation needs can be identified related to renewable energy production, the network and end-user sides require serious efforts in order to fully exploit the opportunities of renewables. We could witness a significant progress at the level of transmission and distribution networks as well as on the end-user side. For instance, ultra-high voltage (UHV) transmission, Li-ion battery energy storage, e-mobility and heat pumps reached the early application stage. In the meantime, digitalization and artificial intelligence are expanding in the energy sector as well. However, further efforts will be needed to improve innovative system integration and end-user side developments.

Many technologies carry future perspectives, yet significant uncertainties remain. For example, smart inverters, compressed-air energy storage solutions and fast charging technologies are already in the demonstration phase and their success depends on further innovation efforts. The future vision of applicability is uncertain for solutions that are currently at a conceptual phase (basic or laboratory-applied research) or prototype level. This especially concerns demand-side areas such as the heavy industry (e.g. steel production, cement industry) and long-distance travels (mainly aviation and maritime travel). In this case, electrification would be hard or too expensive to introduce which perhaps requires different solutions in these areas. *(*Table 13*)*

Basic- and applied research (TRL scale Level 1-4)	Prototype and prototype system (TRL scale Level 5-7)	Demonstration system (TRL scale Level 8)	Early Application (trading system) (TRL scale Level 9-10)	Mature technology (TRL scale Level 11)
Power generation				
• nuclear / fusion • ocean / salinity gradient energy • ocean / wave power technology • PV / Perovskite solar cell • biomass plant CCUS / pre-combustion capture • ammonia turbine	• organic thin-film solar cell • solar thermal electricity / linear Fresnel reflector • offshore floating hybrid energy platform • geothermal / kalina process • coal / post-combustion, polymeric membrane technology • natural gas or coal CCUS / supercritical CO_2-cycle • hydrogen / hybrid fuel cell-gas turbine system • ocean / tidal stream, ocean current	• offshore floating hybrid energy platform • floating solar PV • thin-film PV with natural gas CCUS / post combustion capture, chemical absorption • biomass CCUS / post combustion capture, chemical absorption • biomass plant with CCUS / post combustion capture	• solar PV / crystalline silicon • concentrated PV • seabed fixed offshore wind turbine • large-scale heat pump • solar thermal electricity / parabolic through	• hydropower • nuclear /light water reactor • geothermal / organic Rankine cycle • geothermal / flash process • geothermal / dry steam
• airborne wind energy system		• nuclear / sodium-cooled fast reactor		
• geothermal / enhanced geothermal system (EGS)				
• ammonia co-firing in coal power plants				
	• light water reactor-based small modular reactor (SMR)			
		• hydrogen-fired gas turbine		
	• hydrogen / high-temperature fuel cell			
	• coal CCUS /oxy-fueling technology			
	• nuclear /high-temperature reactor and very high temperature reactor			
	• coal CCUS / pre-combustion, physical absorption			
Electricity infrastructure (including the charging station infrastructure for e-mobility)				
• dynamic charging or electric road system, inductive • distribution / transactive energy	• integration /virtual inertia, fast frequency response (FFR) • smart charging • transmission / supraconducting high voltage	• compressed air energy storage • battery storage / Redox flow • flexible high-voltage grid or flexible alternating current transmission • ultra high-voltage transmission • integration / smart inverter • dynamic line rating • fast charging • dynamic charging or electric road system, conductive	• battery energy storage / Lithium-ion • mechanical energy storage / liquid air energy storage • mechanical energy storage / flywheel • solutions that allow demand-side response (DSR)	• mechanical storage / pumped storage
	• supraconducting high voltage			
Electricity consumption – transport (including batteries developed for transport purposes)				
• battery / multivalent ions (The commonly studied elements of the concept are magnesium, calcium, and aluminum.) • Li-air battery • aviation / battery electric vehicle (for short distances) • aviation / hybrid vehicle • battery / solid-state + Li-metal • Na-ion battery • Li-S battery	• gas hybrid train (internal combustion engine and battery)	• shipping / electric vehicle • Li-ion battery powered truck	• battery electric vehicle / (Li-ion powered passenger car, urban transit bus, light commercial vehicle)	• network-operated electric train
Electricity consumption – industry				
• petrochemical / fossil or biomass-based steam cracker electrification • high-temperature heating / electromagnetic heating for large-scale industrial processes • electric arc and plasma arc furnaces applied to new applications • cement kiln/direct electrification (electrifying the heating process) • iron and steel / high-temperature molten oxide electrolysis (> 1500 ° C) • alumina refining / electrification of the Bayer process	• high-temperature heating / electromagnetic heating for large-scale industrial processes, microwaves • high-temperature heating / concentrated solar power-generated heat for industrial processes • ammonia production / renewable-based, by electrolysis with hydrogen		• low and mid-temperature heating / electromagnetic heating for large-scale industrial processes • low and mid-temperature heating / large-scale heat pump • (hydrogen cell electric vehicle, fuel cell)	
Electricity consumption – building sector				
• solid-state equipment cooling / electrocaloric • evaporative cooling coupled with desiccant evaporative cooling system • air-to-water heat pump / integrated heat pump with storage	• solid-state equipment cooling / magnetocaloric • air-to-water heat pump / membrane heat pump • air-to-water heat pump / high temperature heat pump	• air-to-water heat pump / natural refrigerant heat pump water heater	• evaporative cooling • air-to-air heat pump technologies • ground-source heat pump	• electric cooking • other electric household appliances • dual flow ventilation • natural ventilation
Fuel transformation utilizing electricity				
• hydrogen production / seawater electrolysis • hydrogen production / thermochemical water splitting	• hydrogen production / electrolysis, solid oxide electrolyzer cell	• hydrogen production with electrolysis / polymer electrolyte membrane	• hydrogen production with electrolysis (alkaline)	

Own edit based on IEA (https://www.iea.org/articles/etp-clean-energy-technology-guide)

Table 13 – Technology readiness of low-carbon electricity value chains

Although zero-carbon electricity consumption strongly contributes to climate neutrality targets, electricity alone will not be able to decarbonize the whole economy. In parallel with expanding electrification technologies, introducing other solutions to the market should be accelerated as well. Among other things, **CCUS technologies** will be of key importance in the future. Since Hungary has limited capacities to store carbon, the utilization of captured CO_2 should be primarily in focus when applying CCUS technologies.

CCUS might join the wide range of available low-carbon alternatives in the decarbonization of energy production which would contribute to the zero-carbon transition of fossil fuel power plants (natural gas or biomass powered). Furthermore, CCUS technologies can be key in the future production of natural-gas based low-carbon hydrogen (blue hydrogen) and in industrial production (mainly in cement, iron, steel and chemical production).

Direct air capture[60] – that can be considered as a special form of CCUS – can result in negative emissions which can compensate emissions from sectors that are hard to decarbonize (such as aviation, heavy industry or agriculture). Direct air capture is currently very expensive, therefore this technology sooner or later needs to be applied in a large-scale to reduce its costs.

A key question is whether these energy technologies will be available in time for all phases of the process. The maturity level of technologies for capturing, transferring, utilizing and storing CO_2 emissions is significantly different (Table 14).

While *CO_2-capture* has been present in certain industrial and fuel-transformation processes, such as in ammonia production (chemical absorption), in other fields it has only started to appear on a commercial scale (ammonia production with physical absorption). Also, there are technologies still in the demonstration phase (e.g. methanol production with chemical or physical absorption; cement production with chemical absorption) or at the prototype level (ammonia production with physical absorption; ethanol production from lignocellulose by CCUS technology).

The pipeline technology needed for *CO_2 transport* can be considered as a mature technology. However, transportation technologies on water (mainly maritime) are still at the prototype or demonstration level.

CO_2 has been used in oil mining for more than five decades and the used CO_2 can be stored in oil reservoirs. Storage in underground saline formations is in the early application phase. In the case of other geological storage options (e.g. in depleted oil and gas fields), we have only limited experience for now.

CO_2-utilization is only present in a few sectors, such as urea production and manufacture of carbonated drinks.[61] In the future, CO_2 can possibly be used in construction (within building material) and synthetic fuel production.

To successfully apply carbon capture and storage, further research, innovation and demonstration efforts are needed.

[60] Technology that can capture CO_2 from the atmosphere.
[61] In both cases, CO_2 is stored only temporarily and then emitted into the atmosphere.

Basic- and applied research (TRL scale Level 1-4)	Prototype and prototype system (TRL scale Level 5-7)	Demonstration system (TRL scale Level 8)	Early Application (trading system) (TRL scale Level 9-10)	Mature technology (TRL scale Level 11)
CO_2 capture – Chemical industry (ammonia, plastics, production of other chemical products and refinement)				
• refinement / fluid catalytic cracking, post-combustion capture	• fossil or biomass-based chemical production / physical or chemical absorption		• ammonia / physical absorption • methanol/ chemical absorption	• ammonia production/ chemical absorption
	• fossil or biomass-based chemical production, physical absorption			
CO_2 capture – iron and steel production				
	• iron sponge (direct reduced carbon, DRI product) / physical absorption • iron sponge (direct reduced carbon, DRI product) / based on natural gas based with high levels of electrolytic hydrogen blending • reducing melt by oxygen injection / physical absorption • blast furnace / process gas for hydrogen enrichment and CO2 removal for use or storage, chemical absorption	• converting steel plant gases to fuels (waste gas utilization)	• iron sponge (direct reduced carbon, DRI product)/ chemical absorption	
CO2 capture – cement production				
• electrolyzer-based process for decarbonating calcium carbonate prior to clinker production in the cement kiln	• oxyfuel combustion for CO2 capture • new physical absorption • direct separation • membrane separation • chemical absorption	• partial (21%) CO_2-capture with chemical absorption	• CO_2 capture in inert carbonate materials (mineralization)	
CO_2 capture – hydrogen and other fuel production				
	• production of ethanol from lignocellulose [62] • production of hydrogen from carbon	• biomethane production • bioethanol production from sugar/ starch		
• hydrogen biomass or waste gasification		• production of hydrogen from natural gas by autothermal reforming • steam-methane reforming (SMR) for hydrogen production		
	• biomass / waste gasification			
CO_2 capture – power generation				
• biomass or waste gasification / pre-combustion capture, physical absorption	• natural gas or carbon / supercritical CO_2-cycle • carbon / oxy-fuel technology • carbon / pre-combustion capture, physical absorption	• biomass / post-combustion capture, chemical absorption • natural gas / post-combustion capture, chemical absorption		
		• carbon / post-combustion capture, chemical absorption Direct Air Capture		
	• Direct Air Capture			
CO_2 transport				
	• ship transport / port-to-port		• pipeline transformation	
• ship transport / port-to-offshore				
CO_2 storage				
• mineral storage (e.g. basalt)	• advanced monitoring technologies • depleted oil and gas fields		• underground saline formation	• underground oil reservoirs
CO_2 utilization				
	• synthetic methane from hydrogen and CO_2 • synthetic hydrocarbon fuels / from hydrogen and CO_2	• methanol	• building materials, concrete	• urea production
• synthetic hydrocarbon fuels from water and CO_2 concentrating solar fuels				

Own edit based on IEA (https://www.iea.org/articles/etp-clean-energy-technology-guide)

Table 14 – Technology readiness of the CCUS value chain

Innovative technologies based on **hydrogen and synthetic fuels (produced from hydrogen)** as secondary energy carriers as well as fuel cells as energy source are globally highlighted key areas. These solutions might have a significant role in future sustainable energy systems and mobility as well as in greening sectors that are hard to decarbonize (chemical industry, steel production, cement industry). This is confirmed at the EU-level by the Hydrogen Strategy published as a communication by the European Commission in July 2020 and it will also be supported by Hungary's forthcoming National Hydrogen Strategy. Numerous technologies are needed to produce, transport, store and utilize low-carbon or carbon free hydrogen. These are usually in different phases of the learning curve and are facing their own particular technological challenges. *(*Table 15*)*

Improving pathways to produce low-carbon or carbon free hydrogen as well as laying the foundations of the hydrogen market are critically important. Linking traditional technologies (mainly natural gas steam reforming) with CCUS and electrolysis (using electricity to decompose water) are the two new main production processes. The former can be a mid-term solution while the latter can serve as a good alternative on the long-run – by establishing the carbon-free energy mix. In the case of electrolysis, there are several different processes

[62] Plant materials with cellulose as the main component are called lignocellulose.

known. Alkaline electrolysis technologies are the most mature and therefore the most cost-efficient solutions that dominate the market, especially in the case of large-scale projects. While other new projects are based on polymer electrolyte membrane (PEM) electrolysis or solid oxide fuel cell (SOFC) technologies.

Basic- and applied research (TRL scale Level 1-4)	Prototype and prototype system (TRL scale Level 5-7)	Demonstration system (TRL scale Level 8)	Early Application (trading system) (TRL scale Level 9-10)	Mature technology (TRL scale Level 11)
Production of low-carbon or carbon free hydrogen				
• seawater electrolysis • chemical looping • nuclear/solar - thermochemical water splitting	• coal gasification with CCUS • methane pyrolysis /cracking • solid oxide electrolyzer cell	• electrolysis / polymer electrolyte membrane	• electrolysis /alkaline	
• biomass / waste gasification with CCUS		• hydrogen production by natural gas autothermal reforming with CCUS • hydrogen production by steam methane reforming (SMR) with CCUS		
Infrastructure				
• hydrogen storage in depleted oil and gas field, aquifers	• liquid organic hydrogen carrier (LOHC) tanker • liquid hydrogen tanker	• hydrogen blending in natural gas networks	• fuel charging station • salt cavern storage • ammonia ready tanker	• pipeline • storage tanks
Utilization – fuel transformation				
	• synthetic liquid hydrocarbon fuel production	• synthetic methane production	• fossil-based hydrogen produced by CCUS for petroleum refining	
Utilization – power generation				
	• hybrid fuel-cell gas turbine system		• high-temperature fuel cell	
• ammonia and coal co-firing in coal power plans				
Utilization – industry				
• cement kiln / partial use of hydrogen • iron and steel / hydrogen plasma	• iron sponge (direct reduced iron (DRI) products) / based on natural gas with high levels of electrolytic hydrogen blending • iron sponge (DRI products) / based on 100% electrolyte hydrogen • electrolysis for methanol production	• ammonia production by electrolysis	• fossil-based methanol production by CCUS	• fossil-based ammonia production by CCUS
Utilization – transport				
	• shipping / ammonia-fueled engine • shipping / different types of hydrogen fuel electric vehicle (solid oxide fuel cell, proton-exchange membrane, molten carbonate)	• rail / fuel cell vehicle	• fuel cell for light vehicles (proton exchange membrane) • hydrogen powered train	
	• hydrogen fuel cell for trucks / polymer electrolyte membrane (PEM)			
		• hydrogen tank for road vehicles		
Utilization – building sector				
	• hydrogen-driven heat pump / metal-hybrid heat pump		• hydrogen boiler • combined production of heat and power (CHP) /fuel cell micro-CHP using solid oxide materials or polymer electrolyte membrane • hydrogen-driven heat pump / hydrogen enriched with natural gas or synthetic methane heat pump	

Own edit based on IEA (https://www.iea.org/articles/etp-clean-energy-technology-guide)

Table 15 – Technology readiness of the hydrogen value chain

The National Hydrogen Technology Platform and launching the development of the national hydrogen strategy

The National Energy Strategy, adopted in the beginning of 2020, also addressed the future role of hydrogen. The National Hydrogen Technology Platform, established in April 2020, can give a serious momentum to the development of the Hungarian hydrogen economy since it brings relevant actors to the table. It also creates a forum to establish the incentivizing and regulatory tools based on professional consensus in the focus areas relevant to the Hungarian economy and science. The Platform is aiming to elaborate a white book that maps the domestic situation of the application of hydrogen technologies, the available competencies as well as the expectations and plans of the actors in the sector. The National Hydrogen Strategy will be based on this white book. In order to achieve sectoral progress in this field, it is important to initiate concrete projects beyond the general strategic frameworks.

The large-scale and sustainable utilization of bioenergy – within that, primarily „modern" procedures – will be essential to achieve climate targets. The already mature or almost mature technologies to utilize bionenergy include the production of first generation (advanced) biofuels as well as powering biomass plants and special heaters (Table 16*)*.

Harvesting the long-term potential of bioenergy depends on the development and expansion of several new technologies at early readiness levels. These solutions include advanced (second generation) biodiesel, cellulosic bioethanol production, biomethane production in anaerobic digestion plants, biomass CCUS as well as using biofuels in aviation and maritime transport. However, the cost of raw material and logistical difficulties can limit harvesting the opportunities, hence further innovative solutions are needed to develop and strengthen the biomass supply chain.

Basic- and applied research (TRL scale Level 1-4)	**Prototype and prototype system (TRL scale Level 5-7)**	**Demonstration system (TRL scale Level 8)**	**Early Application (trading system) (TRL scale Level 9-10)**	**Mature technology (TRL scale Level 11)**
		Biomass production		
	• double cropping			
		Bio fuel production		
• biodiesel / gasification + Fischer–Tropsch synthesis with CCUS • biodiesel / hydrothermal liquefaction • biogas and biodiesel / microalgae • biomethane / biomass gasification and biological methanation	• biodiesel / pyrolysis • biodiesel / synthetic isoparaffins • biodiesel / hydrothermal liquefaction • biodiesel / gasification + Fischer–Tropsch synthesis • biodiesel / jet fuel from alcohol • bioethanol / from lignocellulose, enzymatic fermentation + CCUS • biomethane production / biomass gasification and catalytic methanation, with CCUS • biofuel / biorefinery	• biomethane production / biomass gasification and biological methanation with hydrogen • biodiesel / synthetic isoparaffins • bioethanol / sugar and starch from agricultural crops + enzymatic fermentation • bioethanol / from lignocellulose + enzymatic fermentation	• biomethane / biomass gasification (small-scale) • biogas / non-algae raw material, anaerobic digestion • bioethanol / sugar and starch from agricultural crops + enzymatic fermentation • biodiesel / hydrogenated vegetable oil • biodiesel / fatty acid methyl ester	
		• biomethane production / anaerobic digestion and CO_2 separation		
	• bioethanol / lignocellulose, gasification • biomethane production / anaerobic digestion and catalytic methanation with hydrogen • biomethane production / anaerobic digestion and CO_2 separation, CCUS			
		Electricity production		
• **biomass / CCUS, pre-combustion capture, physical absorption**		• biomass / CCUS, pre-combustion capture, chemical absorption • solid biomass powered integrated gasification combined cycle (IGCC)		• solid biomass steam power plant
		Bioenergy infrastructure		
		• mixing biomethane into the natural gas network		
		Bioenergy consumption in the industry		
	• biomass based aluminium refining • biomass based hydrogen • biomass based ammonia	• biomass based ethanol production • other biomass based chemical products	• in charcoal blast furnace for steelmaking • biomass based ethylene production	• „drop-in" fuel technology
		Bioenergy consumption in transport		
	• methanol fuel cell (shipping) • ammonia powered engine (shipping)	• biodiesel powered boat • biojet / for planes • methanol powered boat engine	• ethanol powered engine • methanol powered engine • gas powered engine / compressed biogas • gas powered engine for heavy good vehicles, / liquified biogas • biomethanol, biodiesel for road vehicles	
		Bioenergy consumption in buildings		
			• biofuels / household biogas digester • pellet boiler	• improved biomass fire • biomass-based individual heaters (e.g. wood-burning stove)

Own creation based on IEA (https://www.iea.org/articles/etp-clean-energy-technology-guide)

Table 16 – Technology readiness of the bioenergy value chain

Exploiting the potential of biogas holds serious innovation opportunities in Hungary. Biogas not only would moderate natural gas imports in the foreseeable future, but investments could support job creation and economy stimulation purposes.

6.1.2. Clean technologies and solutions in other sectors

This sub-chapter provides a non-exhaustive overview of clean innovative alternative solutions that are already known for Hungary in the field of water, waste and wastewater management, transport, industry, building sector as well as agriculture and forestry *(*Table 17*)*.

In the past decades, technological development has successfully contributed to the efficient handling **water management** issues. This is mainly due to information-, bio- and nanotechnologies, different up-to-date monitoring systems as well as the water-related application of different methodologies and modelling options that support planning and decision-making. Nevertheless, it is reasonable to exploit the opportunities given by technological developments such as to reduce consumption in water-extensive industries and the number of pollutants of the discharged waters. Furthermore, water management aspects have to be especially taken into account for the electrolysis-based hydrogen production.

The wide-spread application of available clean and innovative **waste management** technologies (e.g. digitalization, membrane technology, artificial intelligence, nanotechnology, plasma technology and modern material technology) as well as establishing and operating environmental management systems is a significant progress. These solutions can expand and make waste management options more efficient in the case of waste recovery, disposal and prevention.

There are available **innovative wastewater treatment solutions** for recycling nutrients into the natural cycle as well as for the disposal of sewage sludge on agricultural lands and energy utilization. Exploiting and further improving these technologies are of key importance.

There is a significant potential in reducing emissions in **transport**, however ceasing further opportunities requires more intensive RDI efforts. Making transport more climate-friendly is supported mainly by cleaner fuel consumption (electricity, first generation biofuels, low-carbon or carbon free hydrogen), but there is further potential in advanced vehicle manufacturing as well (material technology, improving production processes). Moreover, the optimization of fuel consumption efficiency, a more coordinated transport management as well as digitalization and autonomous technologies also hold opportunities.

Using clean technologies, energy carriers and raw materials in the **industry** contributes to the reduction of emissions in the sector and increase energy-, material- and other resource efficiency. In addition to greening and decarbonizing energy consumption, there are many other ways to improve sustainability. Such innovations include the use of lightweight and long-lasting materials, the use of CCUS technology, the use of alternative raw materials, digitalization and automation, robotics, and the improvement of additive manufacturing and process efficiency.

Today, the **building sector** still consumes a significant amount of resources, especially with regard to material and energy consumption. However, with new technologies, significant savings can be achieved in the future. More eco-friendly building and insulation materials as well as new architectural solutions can reduce the sector's material requirements and energy consumption. Clean energy efficiency technologies (solar panels, heat pumps), smart solutions for more efficient energy use as well as modern lighting and ventilation technologies offer a solution for clean and efficient energy use in the sector. In the longer term, there is also great potential for household energy storage solutions.

Agriculture and forestry must also play a serious role in tackling climate challenges.

Agriculture – by its nature – needs a multi-dimensional approach since the sector:

1) must be able to fulfill the increasing demand for food;
2) must reduce its own carbon footprint,

3) and it must improve its resilience against extreme weather.

Possible innovative measures to reduce emissions and improve adaptation to climate change in agriculture include e.g. improving the sink capacity of the soil, integrated plant management and innovative use of agricultural waste. The rise of precision technologies, biotechnology, robotics, drone-based remote sensing or even the expansion of the innovative food industry, that helps transforming consumption patterns, can also contribute to making the sector more sustainable.

Applying innovative „clean" technologies in the agricultural sector

- Energy efficiency measures and a larger-scale use of renewable energy will make a major contribution to reducing the sector's emissions.
- Improving agricultural machinery and equipment as well as greater energy efficiency of agricultural buildings can reduce fuel consumption and the emissions of pollutants.
- The capture and storage of carbon in the soil can be enhanced, inter alia, by cultivation technologies that convert atmospheric CO_2 into carbon-based compounds in the soil.
- The use of nitrogen fertilizers involves significant emissions of nitrous oxide (N_2O), a strong greenhouse gas. Various techniques promise to reduce these emissions but further innovation is needed to increase their efficiency. For example, nitrification inhibitors that can retain nitrogen in the soil for a longer period of time in a form that can be used by plants; microbes that allow plants to capture nitrogen[63] and the production of synthetic fertilizers from renewable energy sources are already known technologies[64]. N_2O emissions can also be reduced by rationalizing the use of nitrogen fertilizers which can be supported by the so-called precision agriculture that applies advanced digitalization technologies (sensors, data transmission, data analysis) allowing fertilizers to get into the soil in the right time and quantity.
- Determining the need for irrigation water as accurately as possible is an increasingly common demand from the crop production sectors, therefore precision irrigation that brings significant savings is the way forward.
- By remote sensing to yield mapping, it is possible to determine where it is worth applying pesticides or manure. Based on the obtained information, more seeds can be applied to good quality soil patches and less to worse-quality areas.
- With the combination of GPS guides and automatic steering, tractors take the smallest possible distance which saves fuel and reduces emissions alongside fuel consumption.
- The efficiency of horticultural greenhouses can be improved with integrated and intelligent systems.
- Precision feeding promotes efficient animal husbandry. Computer-controlled devices with automatic feeders can even allow animals to be fed according to their individual appetite and condition, based on a feeding curve.
- Emissions from animal husbandry (mainly cattle farming) are also significant. Emissions can be reduced through innovative technologies such as innovative feed composition, which, among other things, improve the digestion of cattle.
- Anaerobic fermenters can reduce emissions from manure treatment by capturing methane and converting it into renewable energy.
- Food loss and waste must be reduced. In this regard, while consumption patterns need to be transformed, the opportunities offered by digitalization technologies, that can connect supply chain actors more effectively, have to be better exploited. Based on surveys of the „Without leftover" program of the National Food Chain Safety Office (NÉBIH), there was a 4% decrease in household food waste between 2016-2019. A public awareness raising campaign within the frameworks of the project that included a

[63] This could replace the use of fertilizers in case of certain plants.
[64] WRI (2020). 6 Ways the US Can Curb Climate Change and Grow More Food. Richard Waite and Alex Rudee. August 20, 2020. Available at: https://www.wri.org/blog/2020/08/us-agriculture-emissions-food

complex school program highly contributed to this reduction.

- A wider dissemination of meat and dairy product alternatives can reduce emissions. Many innovations have already been made in this field, and improvements are continuing. Numerous food companies are dedicated to develop and further improve plant-based meat alternatives as well as to elaborate technologies to grow meat in laboratories.

Unfortunately, climate change highly impacts forestry and as such, the sector has to become more innovative in order to face the upcoming challenges successfully. Precision farming must become an everyday practice in forestry and foresters need to adopt technologies such as remote sensing, advanced monitoring systems, light detection and ranging (LiDAR).

Sector	Innovative technologies and solutions
Energy	• renewable energy: bioenergy, geothermic energy (mainly for heat generation) • waste to energy • decarbonized hydrogen and synthetic fuel • nuclear energy innovation • innovative and clean power plant technologies • digitalization technologies and solutions / smart grid, smart measurement and demand side response (DSR), digital power plant and network operation • energy storage technologies (seasonal energy storage, P2G solutions) • efficient and green district heating systems • fuel cell • solutions allowing hydrogen and natural gas blending • CCUS • energy efficiency
Water management	• technologies for efficient water supply • modern water resource management technologies • smart water supply systems • digitalization, monitoring systems • artificial intelligence • bio-, nano- and photo technology • precision irrigation systems • efficient water cleaning technologies
Waste management	Focused on establishing a circular economy: • introduction of innovative production processes that apply less material and mainly use recycled raw material in order to avoid waste • innovative methods for waste collection and transport (e.g. electric waste-collecting vehicles, line optimization); • innovative and green product planning that manufactures long-life, easily reparable products that can be better reused and recycled after becoming waste • promoting waste recycling with establishing smart ecological systems (better harmonization of material and energy flows so that the waste generated by one production phase can become input for another) • environmentally friendly management of non-recoverable waste (besides pyrolysis and gasification, plasma technology could be a new solution)
Wastewater management	Innovative wastewater treatment and environmentally friendly utilization options of sewage sludge • improvement of wastewater cleaning and treatment technologies • technologies promoting recycling • product manufacturing and energy generation from sewage sludge • innovation of remediation technologies
Transport	• e-mobility (electric vehicles, e-charging, smart charging) • hydrogen, fuel cell, hydrogen fueling stations • second-generation (advanced) biofuels

	• fuel efficiency • technologies and solutions that make the operation of public transport systems more efficient • new composite material for vehicle manufacturing • innovative pavement technologies
Industry	• alternative energy use and raw materials (innovative building, insulation and covering materials) • utilization of industrial process heat • material and process efficiency • energy efficiency • CCUS • digitalization
Building sector	• innovative material technology (building material, insulation and covering material) and material efficiency • glass technology (e.g. electrochromic glass, thermochromic glass) • innovative (also clean and efficient) heating and cooling solutions (e.g. heat pumps) • innovative ventilation solutions • household-size small power plant (Hungarian abbreviation: HMKE) • lighting technology (LED) • smart measuring and complete smart home solutions • new planning and construction technologies (modular construction) • energy storage solutions • more efficient household machinery, equipment
Agriculture	• innovative utilization of agricultural waste • precision agriculture • GPS and remote sensing technologies • bio-technology • integrated plant protection • more efficient agricultural machinery and equipment • smart greenhouses
Forestry	• digitalization and monitoring system • GPS and (satellite) remote sensing • light detection and ranging (LiDAR), digital aerial photography • innovative soil management

Table 17 - Summary of innovative technologies and solutions by sectors

6.2. Framework conditions for innovation

Although the most important element of innovation for energy and climate goals is technological innovation, there is also a need for regulations and policies that encourage innovation as well as innovative business models, innovative market design and innovative system operation. As a matter of fact, **there is a need to pursue a holistic approach that emphasizes the importance of interaction between technological and social innovations**.

The role of the state is of utmost importance in the promotion of RDI activities, especially related to the private sector.

The main goal set by the Government for the RDI sector is to make the Hungarian's economy, green and high-tech, as well as resilient and sovereign. This means that as many Hungarian-owned companies as possible should be present in the market, producing and providing world-class products and services with modern and green technology, ensuring a secure livelihood for their employees. Another priority is to increase RDI performance and to fully exploit the economic development opportunities created by the innovation needs arising from climate change.

The New National Strategy for Research, Development and Innovation 2021-2030 is a horizontal document that establishes a favorable, supportive regulatory environment. This document, prior to government decision was based on extensive professional consultation and is the continuation of the Investing in the Future - National Strategy for Research, Development and Innovation 2013-2020. The vertical (sectoral) elements are set out in the Smart Specialization Strategy (S3) that is yet to be adopted.

The EU wish to allocate significantly more budget for the fight against climate change while providing dedicated support for 'green' RDI activities. The available national RDI resources will also increase substantially in the upcoming years. This will be beneficial for the Hungarian economy because according to the findings of a recent evaluation assessing the use of RDI subsidies in Hungary, the resources for RDI were utilized more efficiently from the point of view of the national economy and the market than the investments made in other areas. Although the benefits of these types of aid are slower than others, they can be demonstrated and more durable in the long-term.

To promote green RDI activities the following main domestic strategic goals and implementations tools have been identified:

Strategic objective	Institutions, tools
Establishing and operating a stable state-owned strategic-financing institutional system, and maintaining of the tender system that encourages RDI activities	a) Council of the National Science Policy b) National Research, Development and Innovation Office c) Eötvös Loránd Research Network
Establishing an efficient and successful RDI ecosystem	a) Hungarian Scientific Research Fund (OTKA): to support research projects promoting the international recognition of Hungarian researchers and institutions. b) Thematic Excellence Program (TKP): to support 92 thematic researches of 27 scientific institutions. c) University Innovation Ecosystem: independent organizational units within higher education institutions that promote the market utilization and technology transfer of scientific results of the university as well as support RDI cooperation between the university and actors of the business sector. d) National Laboratories: an internationally recognized, goal-oriented network center system that brings together domestic knowledge centers in topics of particular interest to the national economy in four main areas of research and development (industry and digitalization; culture and family; health and safe society; environment), e) Science Parks: to create a market that is based on one thematic theme. These international business hubs would create a closer cooperation between higher education institutions and the business sector and they would be attractive for green innovative enterprises with a high-value added, a strong job creation potential).
Establishing and operating a supportive environment and dedicated financial institutions for micro, small and medium-sized enterprises using innovative and environmentally friendly solutions to strengthen their	Blue Planet Climate Venture Capital Fund to support business ideas targeting environmental sustainability.

market opportunities	
Occasional tenders for targeted economy stimulus interventions	“Hungarian, high-tech and green” program for the implementation of green developments that enhance the efficiency of Hungarian micro, small and medium-sized enterprises. “Green National Champions" program to support the development that promotes technology-change of technology-related manufacturing businesses with high growth potential related to the green economy and the industry. “The Startup Factory” program to support expert activities and mentoring services of incubators embracing startups. Tenders supporting energy innovation pilot projects.
Continuous dialogue with relevant stakeholders	RDI-related consultations within the frameworks of sectoral forums with representatives of GHG emitting sectors and sinks. In the case of the largest GHG-emitting sector, the Energy Innovation Council has been operating since October 2018.

Energy innovation tenders in Hungary

In March 2020, tenders with an initial budget of HUF 12 billion (which was increased by a further HUF 4 billion in September 2019) were announced to support energy innovation pilot projects. The financial resources were covered by the green economy financing scheme of MIT that is used for allocating the revenues of CO_2 quotas for climate protection. The main objective of the announced tenders is to support the development of innovative solutions and their mass application that promote the domestic use of renewable energies in electricity production and in the field of locally available renewable energy sources. The tenders announced in this round were:

- *Implementation of developments that ensure the stability and flexibility of electricity networks with innovative tools,*
- *Pilot projects that support the establishment and operation of energy communities,*
- *Implementation of developments that transform zero-carbon, excess electricity to gas energy (hydrogen, synthetic methane/biomethane) via innovative technologies,*
- *Securing the energy supply for settlements with alternative supply methods that replace natural gas as well as with modern technologies and flexibility services.*

6.3. Economic development opportunities of clean technology innovation

The role of RDI is crucial in the identification, development and further improvement of low-carbon or carbon-free technologies in all GHG-emitting sector. Additionally, it provides new solutions for adapting to the negative impacts of climate change as well. Furthermore, the RDI sector and new emerging industries that are gaining ground due to RDI offer significant potential for job creation and thus for clean economic growth.

All of the above confirms that RDI activities as well as innovative technologies and solutions will not only allow us to successfully decarbonize our energy production, but they will help reducing emissions in economic processes as well. They will also contribute to fighting the negative impacts of climate change, promote the establishment and expansion of new and sustainable sectors which helps building a new, green and climate friendly Hungary with a healthier society. All this can be achieved in a way that climate goals and economic objectives are mutually reinforcing each other.

7. Governance of the Implementation, Monitoring and Revision

7.1. Governance of the implementation

The adoption and publication of the NCDS is not the end, but rather the beginning of the process that should ensure that Hungary is on the right path to achieve the long-term goal of becoming climate neutral by 2050. Nevertheless, the NCDS will form part of an already existing diverse international, EU-level and national strategic environment (see Annex 2) that sets the frameworks and targets of climate action for Hungary. It is important to take into account the main goals of the NCDS when updating the NECP, the National Climate Change Action Plans and all relevant sectoral strategies.

Climate change is a highly complex phenomenon with cross-cutting impacts, therefore it requires the involvement of the widest and most diverse circle of stakeholders. **Informative, coordinational and harmonizing functions within the public administration** ensure the alignment of different policy areas, avoiding redundant work and appointing people in charge of specific tasks. They will also strengthen the cooperation among these appointees as well as promote reporting about challenges and achievements. To undertake this role, **the executive- and expert-level Interministrial Committee on Climate Change** had been established, which is led by the Deputy State Secretary for climate policy.

For the successful implementation, all relevant and up-to-date scientific and policy related information needs to be gathered. T**his knowledge- and information gathering function** is carried out by an independent scientific institution's periodical National Climate Change Assessment Reports, following the example of the IPCC and other climate-related data-gathering.

The continuous and structured dialogue with non-central governmental stakeholders could foster joint action as well as promote informing the public regularly and taking their inputs into consideration:

a. Specific conciliation forums in every GHG emitting and sink sectors as well as in cross-cutting areas consist of governmental and non-governmental stakeholders,

b. Green Financial Working Group that is dealing with the financial aspects of the implementation,

c. County-level Climate Platforms,

d. And such government-operated online platforms that ensure the access to up-to-date information and provide a possibility for anyone to share their feedback.

The **main tools of the implementation of the NCDS** are **documents that prescribe concrete actions and programs** to achieve short- and medium-term goals harmonized with long-term objectives, these are mainly

- the 3-year-period Climate Change Action Plans created for the implementation of the current National Climate Change Strategy,
- and the National Energy and Climate Plans for 10-year periods**.**

Furthermore individual **policy strategies** (for example the strategy aiming to establish the hydrogen economy) or other relevant documents are also implementation tools for the long-term goals of the NCDS.

7.2.Monitoring and Monitoring, Reporting and Verification (MRV)

In the process of achieving climate neutrality the impacts of implemented policy measures become known as well as several intended and unintended changes occur which need to be monitored and reacted to. During the implementation of the NCDS, **the covered areas need to be monitored** in order to provide the most appropriate social, economic and environmental response measures.

First and foremost, the successful implementation of the NCDS requires the close monitoring and evaluation of GHG emissions, ensuring an appropriate measurement as well as the continuous improvement of the monitoring system. Monitoring GHG emissions is carried out according to the strict measures identified by the Conference of the Parties (COP) to the UNFCCC and the EU, following the detailed methodology guidelines of the IPCC. The comprehensive National GHG Inventory Report, in line with international and EU regulations, is published annually on the website of the UNFCCC and the European Commission. The most important tools for monitoring and evaluating GHG emissions are the reports submitted to the UNFCCC and to the European Commission.

For future adjustments, it is important to monitor the implementation of the NCDS and the impact of its interventions, alongside GHG emissions. Instead of introducing new monitoring processes, relying on existing methods should be encouraged such as the ones used for the NECP.

7.3. Revision

The NCDS should be considered as a „living” document, therefore its implementation needs to be monitored, reviewed from regularly – mainly based on international and EU policy changes – and adjusted if necessary. The schedule of the revision should follow the revision cycle of the Paris Agreement and the EU while taking into account:

- the reports submitted to the UN and European Commission and their independent expert evaluation,
- the most recent available scientific results and policy information,
- the results of stakeholder consultations,
- the opinion of the Scientific Advisory Board on Climate Change and the findings of the National Climate Change Assessment Reports,
- and the practical experiences of the NCDS implementation.