

Measuring the Climate Risk Exposure of Financial Assets – Methodological Challenges and Central Bank Practices*

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In order to understand climate-related risks and opportunities, the availability and transparency of reliable financial information is essential. In this regard, the financial sector plays a special role owing to its ties to other economic sectors, and the exposure of financial institutions highlights the responsibility of central banks. This paper uses the literature related to environmental sustainability reporting as well as practical experience to describe the challenges encountered in assessing the green risks of financial assets (absence and heterogeneity of data, differences in definitions and requirements, lack of a uniform methodology, limits of rating schemes) and also details the climate risk measurement methodologies and practical solutions employed by central banks publishing their own climate-related financial disclosures, i.e. the Bank of England, the Banque de France and the Magyar Nemzeti Bank.

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1. Introduction

According to a report by the Intergovernmental Panel on Climate Change from 2021 (IPCC 2021), an unprecedented climatic change is underway, as the atmosphere, oceans and landmasses are heating up due to human activities. The rate of sea level rise and permafrost thawing has increased, and there are more and more extreme weather events, with increasingly serious consequences. The impact of this may be especially complex (Zöldy *et al.* 2022), which is shown by the fact that – in analogy to Nassim Nicholas Taleb’s black swan¹ – many refer to climate risks and the green transition in finance as a ‘green swan’ (Bolton *et al.* 2020).²

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¹ Taleb (2007)

² The BIS held a Green Swan Conference in June 2021, where Agustín Carstens delivered a speech on the importance of transparency and measuring and reporting risks, pointing out the development of metrics and stress tests (*Transparency and market integrity in green finance*). The Green Swan Conference, Basel, 2 June 2021. <https://www.bis.org/speeches/sp210602.htm>. Downloaded: 9 February 2022).

Mitigating and halting climate change requires enormous financial resources. According to a World Bank estimate, between 2015 and 2030, investment in infrastructure amounting to USD 90 trillion globally would be needed to achieve the climate objectives (*UN 2021*), while the OECD estimates that investments in the order of USD 6,900 billion are needed to meet the climate goals stipulated in the Paris Agreement (*OECD 2020*). Another telling piece of information is that the COP 26 climate summit held between 31 October and 13 November 2021 focused partly on financing the efforts against climate change.³ Certain countries have already embarked on the path of green transition for their economies, and many companies are working to make their operations sustainable. However, this will not be sufficient to ensure the transition to a sustainable, green economic model, as governments and firms will also need to forge ‘strategic partnership’ with participants in the financial system (*Matolcsy 2021*).

One of the basic preconditions for the transition to green finance is knowing the climate exposure of individual economic entities and assets. This requires transparency, which is crucial for building trust,⁴ while the risk of ‘greenwashing’⁵ remains high (*Alogoskoufis et al. 2021a*). The financial sector plays a special role in all of this, as banks and other financial service providers have ties to the entire economy via financial intermediation. In other words, the climate risks of the financial sector⁶ reflect the climate risks of the economy as a whole, as the system is interconnected (*Kolozsi 2021*). The significance of the financial system is further boosted by the fact that the green transition of economic operations and switching to a net-zero economy requires that the financial system be able to finance an appropriate amount of green investments, but major changes are necessary for that (*Carney 2021*).

Transparency represents value added for society, and it highlights the importance and responsibility of central banks in the case of the financial system.⁷ In recent

³ *COP26 Reaches Consensus on Key Actions to Address Climate Change*. Press Release, United Nations Framework Convention on Climate Change (UNFCCC), 13 November 2021. <https://unfccc.int/news/cop26-reaches-consensus-on-key-actions-to-address-climate-change>. Downloaded: 9 February 2022.

⁴ *Setting New Standards: An Interview with Julie Becker of the Luxembourg Stock Exchange*. State Street, November 2018. <https://www.statestreet.com/ideas/articles/setting-new-standards.html>. Downloaded: 9 February 2022.

⁵ According to *Delmas – Burbano (2011)*, greenwashing is defined as firm behaviour where companies engage in positive communication about environmental performance, while actually exhibiting poor environmental performance.

⁶ *Eceiza et al. (2020)* argue that 15 per cent of European bank balance sheets may be affected by climate risks, but their extent is yet to be explored. The financial system is highly interconnected, and it follows from this that individual financial institutions alone cannot mitigate financial stability risks (*FSB 2020*). The financial sector has close ties to real economy actors, so the banking system is also exposed to considerable real economy risk: if such stakeholders suffer losses, their lending activity may decline, which may undermine economic growth (*Baranović et al. 2021*). Climate risk regulations not only entail higher costs but also an opportunity to explore the related risks more accurately (*Calice – Caruso 2021*), although this is significantly hampered by the lack of data (*FSB 2020*).

⁷ For more on transparency and the development of green financial markets, see, for example: *Kahlenborn (2001)* and *Talbot (2017)*.

decades, the social role and influence of central banks has received increasing attention (*Siklos 2017; Lentner – Kolozsi 2019*), and central banks have shifted towards more transparent operation the world over, in line with the principle of democratic accountability. Central bank transparency is also relevant when it comes to measuring climate risks, since the central bank – as a public institution – should be expected to explore climate risks on its balance sheet not only because such risks can lead to potential losses, but also because the central bank may affect the climate consciousness of the other players in the financial sector, foster the development of best practices in measuring climate risks and set an example for commercial banks as well (*Campiglio et al. 2018; Dicaud – Volz 2021*).

2. Thesis questions and the analysis methods used

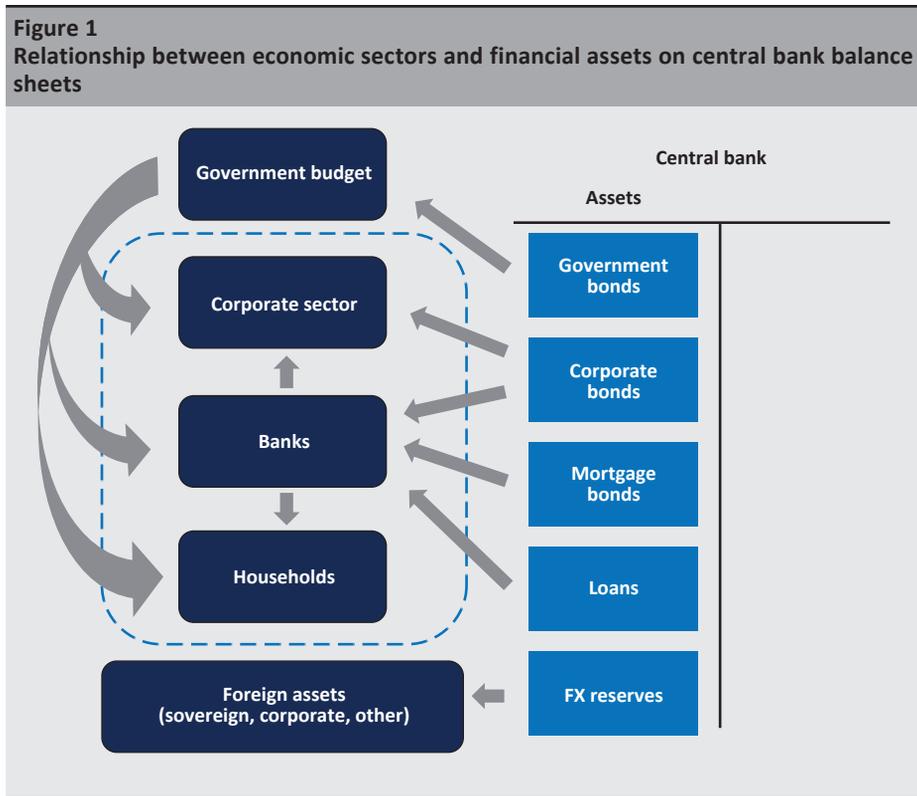
The practical manifestation of green transparency is the measurement and reporting of the climate risk exposure of financial assets. This paper presents the methodological challenges and practical solutions of the climate risk analysis of central bank balance sheets, which clearly shows the limits and opportunities of this novel analysis, and may be used as a point of reference for the balance sheet analysis of other players in the financial sector; thus, it has broader applicability than the relatively narrow realm of central banking.

The following issues were examined:

- (1) Challenges that can be identified during the climate risk analysis of financial assets, in particular items that are relevant for central bank balance sheets.
- (2) Practical solutions for addressing such challenges, as utilised by international recommendations and the central banks preparing climate-related financial disclosures.

This analysis focuses on assessing the exposure to climate risk of the relevant central bank balance sheet items and examines ways to report on financial account items in terms of climate risk, for whatever reason (e.g. regulatory requirements, demands by external stakeholders, personal commitment of executives). This means that the study does not cover the building of models that address the integration of climate considerations into financial decisions. Other aspects of sustainability (including the non-environmental facets of the ESG approach) are also not discussed here. Due to the nature of central bank balance sheets, the analysis covers a wide range of assets, as such balance sheets include SME and large enterprise loans, corporate and bank bonds as well as government securities, from not only domestic but possibly also foreign issuers. Due to the comprehensiveness objective, the analysis of the financial assets on central bank balance sheets has to cover the complete range of sectors and liabilities (*Figure 1*), even though such instruments may vary

widely in their nature and the applicable measurement framework, and thus can only be compared partially, with some limitations.⁸



Exposure to climate risks, including the risks of financial institutions, can be divided into physical and transition risks, and this analysis covers both. *Physical risk* means that the change in climatic conditions, such as the rise and variability in average temperatures, a shift in the amount and distribution of precipitation, including droughts and floods, might affect the value of the financial assets on institutions' balance sheets. Physical risks come with a significant tail risk, i.e. low-probability events entailing large losses. The realisation of physical risks can suddenly and substantially reduce the price of the relevant assets, potentially leading to a shock, which in turn can have a destabilising effect in the entire financial system. Physical risks can be concentrated in certain industries or countries. *Transition risks* refer to situations when the value of financial assets changes in relation to the transition to a low-carbon economy. In the case of transition risks, faster-than-expected change in economic policy can cause a shock to the financial system.

⁸ These include the differences between sovereign and corporate claims (government securities and corporate bonds).

The relative novelty of the thesis question and the issue called for special analysis methods. The examination was based on three main methodological pillars:

- 1) Review of the relevant literature, with a special focus on sources with experience in practical implementation (meta-analysis),
- 2) Description of international practices, in particular the climate-related financial disclosures produced by the Bank of England (BoE) and the Banque de France (BdF) as well as discussions with experts from these banks,
- 3) Experience gained from preparing the climate-related financial disclosure of the Magyar Nemzeti Bank (the central bank of Hungary, MNB) in 2022.⁹

3. Practical challenges in implementing climate risk transparency

When it comes to climate risks, the impact on bank balance sheets cannot be examined with the usual methods (*Baranović et al. 2021*), and measurement of the risks is all the more difficult because of the potential non-linear nature of the effects, and thus certain developments and events may entail larger losses than anticipated.

Based on the literature and the established practices, a summary of the most relevant challenges in measuring climate risk exposures is presented below. The challenges listed here arise not only in measuring climate risks for central banks, but also more universally, and they are also relevant for central banks' climate risk assessment due to the wide range of financial assets on central banks' balance sheets.

The measurement of climate risk exposure rests on the two pillars of data and methodology, and thus the challenges can also be identified in these two areas.

3.1. Data

3.1.1. The availability, amount and quality of data

Capturing climate risk exposure considerations requires high-quality, systematic and available input data (for investors and reporting entities alike), structured and processed by various models. According to the Basel recommendations (*BIS 2021*), climate risk as a risk factor can be categorised as a traditional risk (driver), so its

⁹ The authors of this study helped prepare the MNB's climate-related financial disclosure as project leaders and experts.

impact can be translated into credit risk, market risk and liquidity risk,¹⁰ but climate risk exposures can also be analysed and assessed outside these categories, ‘in their own right’.

If assets’ climate risk exposure is sought to be analysed, challenges may be encountered in terms of coverage. Currently, most market participants fail to disclose sustainability data (*TCFD 2021*). In the early stages of market development, reporting entities mainly focus on the corporate sector, the sector most exposed to climate risk, in particular the companies that are most in demand by investors (*EF 2021a*) and that offer a wider range of data. As a result, data from smaller firms is either missing completely from these databases or only approximate values are given for them, and climate risk exposure measures are assigned based on sector or geographical location rather than company-specific data (*Edwards et al. 2021*). The MNB’s experience¹¹ shows that sovereigns are in a similar situation, in that providing structured data has not been a primary goal for reporting entities, as the required methodology differs from that pertaining to the corporate sector. As regards the coverage of the household sector, the issuers of new green mortgage-covered bonds are faced with a challenge because there is no database on historical energy data of homes (*Wass 2021; Nagy et al. 2021*). Another challenge is that the data available at the reporting entity level usually describe the issuer or company, while issue-specific information may be more relevant in certain cases, as assets may be covered and the financed projects may differ.¹² It is not sufficient to examine climate risk exposures in themselves, because it has to be assessed how much a given company, debtor or issuer can withstand a potential climate risk stress (*Lancesseur – Lorans 2021*).

¹⁰ As regards access to market data, the basic level contains the disclosures of issuers and companies, which should be compiled, analysed and assessed. A major portion of such tasks have been ‘outsourced’ by market participants even on the traditional bond market, for example to various credit rating agencies and reporting entities, which thus facilitate increased market transparency. This market segment can also be traced on the market for green assets. Although consolidation is underway, there are several service providers on the market right now, with a highly heterogeneous product range (*ESMA 2021; Bloomberg 2019; Environment analyst 2019*) and varying levels of quality. On the one hand, having many market participants is useful because it generates competition and encourages development in the services sector, but on the other hand it does not promote the establishment of uniform procedures, and the homogeneity of data and reports is poor overall.

¹¹ This finding is based on the experience gained during the preparation of the MNB’s climate-related financial disclosure. The MNB used the available central banking examples (e.g. *BoE 2021; BdF 2021; ECB: Alogoskoufis et al. 2021b*) and also consulted with individual central banks and reached out to established reporting entities on the market to gather information on reporting, product range, coverage and methodologies.

¹² This may be especially important in the case of green bonds.

3.1.2. Heterogeneity

Heterogeneity is a huge challenge in the implementation of efficient and uniform disclosure practices. Reporting entities disclose their climate risk exposure reports for various reasons and in different forms (TCFD 2021). Investor expectations about reports also vary, and the assets are also different. Therefore, all in all the heterogeneity of supply and demand and the expectations by reporting entities and users pose a massive challenge in establishing uniform disclosure practices (Table 1), which of course also affects the opportunities of the entities, for example central banks, using these reports directly or indirectly in their own climate risk analysis.

Table 1		
Potential reasons for the heterogeneity of climate risk exposure data		
Debtor type	Investor type	Asset type
Reporting opportunities and resources vary by debtor Examples: – retail mortgagor* vs. professional corporation – carbon-intensive vs. carbon-neutral industry – regulatory expectations vs. investor expectations	Demand for information may differ by investor Examples: – retail investors vs. banks offering green loans – neutral investors vs. fund buying green bonds – special target function of ethical investors**	Type of financial assets determines reporting Examples: – rating requirement of household mortgages vs. commercial real estate mortgages – rating requirement for standard vs. green bonds vs. bonds tied to a sustainability goal
Note: *In the case of households, information and attitude are also crucial. For more on this, see: Bethlendi – Póra (2021). ** These investors may primarily strive to understand the transition paths presented in TCFD reports as well as the implemented or planned steps to achieve the Paris climate goals. Traditional investors seek to strike a balance between risk and returns, while ‘green investors’ may also focus on climate VaR calculation, stress testing and the creation of a scoring system.		

Another challenge in connection with heterogeneity is the lack of validation. The principal–agent problem is quite pronounced on the market for green assets. Even in the case of traditional bonds, although rating is performed by an external party, the credit rating agency, that agency is typically financed by the issuer. In the case of green bonds, having an external, independent credit rating agency may not be required, as issuers are responsible for producing their own reports and compiling data (MNB 2022). Therefore, even entities in the same sector and financing similar projects may exhibit different effects, and such data cannot be validated.

3.1.3. Limits to the usability of credit ratings

On the traditional securities market, investors can also gain a picture of the risk profile of their portfolio using credit ratings. As part of the rating process, credit rating agencies need to take into account sustainability risks, but only if they exert a meaningful financial impact at the relevant 3–5-year rating horizon. As climate risks have a longer horizon than that¹³ traditional credit ratings only have limited applicability from a sustainability perspective, and climate risks have not been incorporated into credit ratings in the form expected by the market.¹⁴

Utilising the environmental component of the ESG ratings used as a proxy for sustainability data may be misleading in capturing climate risk exposures. Several reporting entities prepare an ESG rating, but (1) there is a weaker correlation between the ratings of the different service providers than in the case of traditional credit ratings, and (2) the weighting of the climate risk aspect used in ESG ratings also varies, so it has limited use in capturing climate risk exposures (*Berg et al. 2019; Dimson et al. 2020*). Unlike on the market for credit rating agencies, there is no uniform European regulation in effect pertaining to ESG rating agencies and their ratings, which is detrimental to comparability and transparency (*ESMA 2021; IOSCO 2021*).

3.2. Methodology

3.2.1. Metrics used and modelling limitations

Besides coverage and data quality, the market also faces challenges in connection with the metrics and methodologies used. One key issue is that certain metrics may not have a straightforward interpretation, and comparability across different issuers (e.g. sovereigns and the corporate sector) is problematic due to divergent methodologies.

- *Appropriateness of time series.* One precondition for climate risk exposure modelling is the availability of data of sufficient quality and quantity. The length of the available time series and the amount of data are limited because only Europe

¹³ Carney, M.: *Breaking the tragedy of the horizon – climate change and financial stability*. Speech at Lloyd's of London, London, 29 September 2015. <https://www.bis.org/review/r151009a.pdf>. Downloaded: 9 February 2022.

¹⁴ As regards climate risk factors, certain credit rating agencies offer climate-adjusted PD and rating besides the traditional ratings (e.g. S&P Climate Credit Analytics, Climate Risk Gauge). There are reporting entities that calculate their own PD effects using models (*Janosik – Verbraken 2021*). Fitch has a service called ESG Relevance Scores, which helps investors determine the relevance and weighting of different ESG factors in credit ratings. According to the analysis of Fitch, environmental effects currently have a low significance in its credit ratings: for example, only 3.1 per cent of the credit rating of non-financial corporations considered this a major factor (*Fitch 2021*).

and the US have major securities holdings,¹⁵ but even this market is dwarfed by traditional markets, and green markets are also relatively young. The liquidity of securities may also pose a challenge (*Fender et al. 2019; Boutabba – Rannou 2022*). Another crucial issue when it comes to modelling is the relevance of historical data in projections.

- *Heterogeneity of metrics.* On the traditional securities market, credit ratings condense information well, and they are comparable in terms of their methodologies and results. Climate risk exposure analysis is less developed than this. There is a market consensus that risks should be analysed by dividing physical and transition risks. However, different reporting entities analyse different drivers of physical risks, translating climate risk exposures into relative riskiness, for example producing a score of 0–100 (*BoE 2021; BdF 2021*), while others use financial indicators, for example the CVaR (*MSCI 2020*) for this purpose. The same applies with regard to transition risks: the energy mix is usually used for sovereigns, while basic carbon-exposure indicators are used for firms (*Faiella et al. 2021; BoE 2020*).
- *Interpreting the metrics.* According to TCFD recommendations,¹⁶ the most widely used metric is weighted average carbon intensity (WACI), which is presented in more detail in the section on methodological questions. However, there are a number of unresolved questions in interpreting the WACI, which is also acknowledged by the TCFD (*TCFD 2017*). First, the metric is difficult to use in itself, since an entity's total CO₂ emissions may rise even when the WACI shrinks. In sovereign WACIs, there are no uniform practices for using either nominal or PPP-based GDP, the currencies and exchange rates that are relevant for calculating this metric, and distortions may be caused because typically national economy figures are calculated for sovereigns. In the case of companies, sector definitions and the utilisation of the relevant average WACI values may also be misleading, as companies may vary widely within the same sector, so using company-specific information is difficult to avoid, but there may be significant data constraints in this area.

¹⁵ There is wide variation globally in green bond issues. The first green bond was issued by the European Investment Bank (EIB) in 2007, while the first Western European green mortgage-covered bond was issued in 2015 (*Kidney 2015*). However, the first Hungarian green securities were only issued in 2020, and mortgage-covered bonds have only been issued since 2021. Besides the age and size of the market, its liquidity is also important, and certain targeted initiatives also help boost liquidity (e.g. German and Dutch twin bond issues). Banks are also increasingly seeking to utilise the positive risk opportunities presented by green lending, which is also supported by supervisory authorities through preferential capital requirements (*Billio et al. 2020; MNB 2020; MNB 2021a; MNB 2021b*).

¹⁶ Task Force on Climate-related Financial Disclosures

3.2.2. Definitions and requirements

A central issue related to the green asset market and its continued development is the existence of a uniform, accountable set of definitions and requirements for the different parameters. Reporting is based on defining the parameters along which loans and securities can be deemed green, as well as the uniform procedure for disclosures (*MNB 2022; EF 2021b*).

- *Missing and different definitions.* Besides laying down disclosure requirements, regulators also play an essential role in connection with the definition of securities and loans. Centrally determined requirements can address greenwashing, improve standardisation, comparability and market efficiency, and also provide a solid basis for continued development. Relevant regulatory requirements may include aspects determined at the EU level,¹⁷ but countries and central banks may have their own special requirements as well.¹⁸ Along with the regulatory authority, the central bank asset purchase programmes also determine requirements (*MNB 2021c*). In this respect, regulation follows the development of green securities markets with a lag.¹⁹
- *Parallel standards.* The market standards determined by the Climate Bonds Initiative (CBI) and the International Capital Market Association (ICMA) (*CBI 2019; CBI 2021; ICMA 2021a*) are the most widely used on the green securities market, and although they are not binding regulations, they can be used as points of reference. In addition to the sustainability definition, another advantage of the standards is that they lay down principles for disclosure. On the green securities market, these standards provide a very similar framework of definitions, but they also entail highly divergent regulations in terms of disclosures and issues, which hampers the development of a uniform procedure on the market. Verifiers assess the frameworks and evaluate their compliance with these standards, but besides controls, issuers also play a vital role in establishing sustainability conditions and ensuring compliance with the requirements. The reports published by the verifiers are heterogeneous in their scope and content,²⁰ and issuers' green frameworks are

¹⁷ The EU's green taxonomy has been adopted, but the technical details have not been fully developed and implemented (*EU 2020; EU 2021a*), the EU's green bond standard is being prepared (*EU 2021b*), so there is currently no international regulation setting out uniform requirements for the parameters of sustainable financing objectives or sustainable financing transactions.

¹⁸ One might think of different regulations on mortgage-covered bonds. Hungarian regulation (*JHT 1997*) does not treat green and non-green bonds differently, unlike for example the requirements in Luxembourg (*LUX 2018*), which are unique in the EU for now, due to their green focus. The EU's rules on mortgage-covered bonds (*EU 2019*) are consistent with Hungarian regulations, but they do not have a green focus.

¹⁹ There are currently no capital market laws on investor rights related to green bonds, issuer obligations and legal consequences.

²⁰ For example, in the case of Hungarian green mortgage-covered bonds, all four issues conducted until the end of 2021 occurred with a different rating (OTP: https://www.otpbank.hu/OTP_JZB/file/JZB_Fuggetlen_jelentes_2021.pdf; Unicredit: https://www.unicreditgroup.eu/content/dam/unicreditgroup-eu/documents/en/investors/ESG-investors/Sustainability-Bonds/UniCredit_SPO_18_6_2021.pdf; ÁKK: <https://akk.hu/download?path=974f9745-4920-4979-a389-ca51a3a02cec.pdf>; Takaréék: <https://www.takarekjbz.hu/files/22/84149.pdf>).

also detailed to varying degrees, and there are no uniform disclosure requirements defined by the standards for impact reports.²¹

- *Green default problem.* There is no central register for the reports,²² and if issuers deviate from the recommendations, they do not face clearly defined legal consequences. Standards are typically applied on a voluntary basis, which undermines accountability, since there is no formally determined sanction for deviating from the standards ('green default'). This also means that as green frameworks are usually not part of a bond's basic documentation, issuers have significant room for manoeuvre, while investors can only respond to issues by selling the bond, and no other legal options are available to them.²³

Securities market segments function appropriately if the market ecosystem built around them functions efficiently and well (*mature markets*²⁴). This includes the 'voluntary' development of procedures and practices, just like the binding regulatory expectations. Unlike the traditional bond market and mortgage market, the green asset market ecosystem has not yet solidified it is still a work in progress. In this context, the most important parts of the system (investor base, issuers, best practices on the market, regulatory requirements, cleansing of the market and services of data providers) change and develop dynamically. This can also influence climate risk exposure transparency: a more mature and thus more stable market is more likely to develop generally accepted standards that enable environmental sustainability reporting.

²¹ For example, ICMA publishes a list of metrics (*ICMA 2021b*), but it is not binding for the issuers, and thus the impact reports published by issuers vary widely: certain issuers provide information at the project or security level, while others do so for the entire portfolio, with differences in format, scope of the reported data, metrics used and reference date (see, for example: *ADB 2021; EIB 2020; KfW 2021*). The MNB's FX reserves have included a dedicated green bond portfolio since 2019 (*MNB 2019*). The MNB first prepared a publication on the climate risks of the portfolio in 2021 (*Elek et al. 2021*); the backbone of that analysis was the compilation and assessment of issuers impact reports. In the course of this work, the MNB consulted with certain issuers and other organisations holding green bond portfolios, and it faced similar challenges in preparing the report as other market participants (*EF 2021b*).

²² Companies on the market have started compiling impact reports and selling the related service as a product, with varying coverage (e.g. Green Asset Wallet). Currently, investors can typically rely on their own compilations when it comes to impact reports, requiring huge resources (*EF 2021b*).

²³ The EU's green bond standard is expected to be a major step forward in this regard.

²⁴ The maturity/immaturity of markets and the reliability/absence of data and models also affect prices. Despite the relevance of climate risks, estimates suggest that current asset prices do not incorporate climate risk considerations (*Mastouri et al. 2021; Stroebel – Wurgler 2021*).

4. Central bank practices in measuring exposure to climate risks

The following chapter presents the key international recommendations for climate exposure reporting as well as the available practical examples for analysing central bank balance sheets.

Having recognised the challenges posed primarily by the information gaps and the lack of uniform methodology, the G20 Financial Stability Board created the Task Force on Climate-Related Financial Disclosures (TCFD) in 2015 to identify the necessary information that facilitates the assessment of climate-related risks and opportunities. Climate-related reporting requirements used to vary widely (*OECD 2015*), and therefore the establishment of the TCFD and its harmonisation efforts so far are major milestones on the road towards transparent climate-related financial disclosure (*Carney 2020*).

In 2017, the Task Force published its recommendations, which are organised around four thematic areas and can be adopted by wide range of institutions and organisations (*Figure 2*). The four areas (governance, strategy, risk management and metrics and targets) represent the main operational elements of economic entities, thereby enabling the interpretation and implementation of the recommendations. As transparency improves, climate risks can be appropriately incorporated into strategic decision-making processes, facilitating more efficient market prices and the capital flows necessary for a green transition.²⁵ The present study focuses on metrics and targets.²⁶

²⁵ The TCFD recommends that the disclosure on climate-related risks and opportunities form part of organisations' annual reports (e.g. *DNB 2021*). This is because most financial supervisory authorities and international requirements compel publicly traded companies to publish material information in their annual financial reports.

²⁶ The financial sector's TCFD reporting practices are summarised by *Carlin – Fischer (2020)*.

Figure 2
Four main areas of climate-related financial disclosure



The publication of reports analysing climate risk exposures has not yet become widespread among central banks.²⁷ The Bank of England publishes its analysis on climate change in a separate report, while the Dutch central bank incorporates its results into its annual report, providing little detail. One should also mention the French central bank's Responsible Investment Report (*BdF 2021*), which examines sustainability issues on a broad horizon, covering other risks besides climate change. The methodology of the central banks publishing a separate TCFD report, i.e. the Bank of England and the Banque de France is presented below, along with the methodological background of the Magyar Nemzeti Bank's upcoming TCFD report²⁸ pertaining to the climate risk exposure analysis of financial assets.

²⁷ Since the establishment of the Network for Greening the Financial System (NGFS) in 2017, an increasing number of central banks and financial supervisory authorities have been actively working to ensure that the objectives in the Paris Climate Agreement are met, that the global financial system can better address climate risks and that capital flows facilitate green and low-carbon investments. The strategic objectives of the NGFS are achieved, for example, by developing and popularising best practices for its members. In the course of this, the NGFS set up working groups in 2021 to assess climate risks and prepare TCFD-compatible reports. The NGFS strives to establish best practices to ensure the better comparability of central bank reports (*NGFS 2021*).

²⁸ When the present paper was submitted for publication, the MNB's TCFD report was still being prepared. The methodology of the MNB's climate-related financial disclosure was designed taking into account three factors: TCFD recommendations, existing central banking publications, available data.

4.1. Transition risk

Transition risk refers to situations when the value of financial assets changes in relation to the transition to a low-carbon economy. Three indicators measuring the transition risk of (central bank) portfolios are presented below, with a special focus on their relevance for the MNB's climate-related financial disclosure:

- WACI,
- brown share of the portfolios,
- energy mix.

4.1.1. Weighted Average Carbon Intensity

The TCFD recommendations include a WACI indicator used for quantifying indirect greenhouse gas emissions. It was directly developed for analysing corporate portfolios and was adapted for sovereign assets by the MNB, as in the analyses of the British and French central banks. This metric quantifies the average carbon intensity of portfolios, weighted by the share of the assets within the portfolio.

The MNB analysed the climate-related impact on financial portfolios using end-2021 balance sheet data as well as the latest available greenhouse gas (GHG) emission information and the corresponding GDP data, using the 2019 GHG and GDP data for FX reserves and 2020 data for Hungarian assets. For most portfolios, data come from Eurostat databases, with the exception of the FX reserve portfolio, which also has a large exposure to entities outside the European Union.

- The government securities purchase programme and the corporate exposures, such as the Bond Funding for Growth Scheme (BGS), the Funding for Growth Scheme (FGS) and large enterprise loans, were analysed using data from the Eurostat Air Emission Accounts also available in breakdown by sectors (based on NACE Rev. 2 codes).
- The carbon-intensity of FX reserves was calculated using the UNFCCC's National Inventory on GHG emissions and the GDP data from the OECD and World Bank databases.

To take a practical example, the average carbon-intensity of sovereign portfolios measures the GHG emissions necessary for the production of one unit of GDP. In 2021, the average carbon-intensity of the sovereign exposure in FX reserves was 287 tonnes of CO₂e/EUR million in GDP. This means that during the economic activity financed by FX reserve investments, GDP worth EUR 1 million was produced while entailing greenhouse gas emissions of 287 tonnes in CO₂ equivalent.

With respect to the carbon-intensity methodology used for sovereign portfolios, the MNB employed a similar approach as the previously published reports by the BoE and the BdF (Table 2). The BoE also used UNFCCC GHG emission data to analyse its portfolio. GDP data were taken from the World Bank database, however, the WACI’s denominator used GDP data measured at purchasing power parity rather than nominal GDP. The advantage of the carbon-intensity calculated with nominal GDP is that it ensures greater consistency in the analysis of various asset classes, which is an important principle in the TCFD recommendations. By contrast, PPP GDP is a statistical measure specifically used in international comparisons, adjusting for the distortions caused by different price levels. The issue of the GDP used in the denominator can cause major differences mostly in the case of developing countries, so the MNB’s report also describes this methodological aspect in connection with Hungarian government securities purchases. Unlike the MNB and the BoE, the BdF used a third-party analysis firm (Trucost) to prepare its report. The calculation formula of the WACI is the same in the BdF report, but no information was given on the source of data. Nonetheless, third-party analysts also usually base their analytical activities on publicly available databases.

	Magyar Nemzeti Bank	Bank of England	Banque de France
Formula	$WACI = \sum_i \frac{\text{market value of exposure}_i}{\text{market value of the portfolio}} * \frac{\text{GHG emissions of the country}_i}{\text{GDP of the country}_i}$		
GHG data	UNFCCC National Emissions Inventory	UNFCCC National Emissions Inventory	The BdF did not provide more information on its chosen data sources
GDP data	OECD, World Bank: nominal GDP	World Bank: GDP measured in PPP	

The carbon-intensity methodology of corporate portfolios used by the MNB and the other two Western European central banks differ, related to the data access challenge addressed in the paper (Table 3). The overwhelming majority of the corporate exposures of the BoE and the BdF are held against global corporations that publish a detailed report on their revenues and spearhead GHG emissions reporting efforts. Under pressure by various stakeholders (e.g. regulators and consumers), the largest companies in the world have started reporting on their GHG emissions: the corporate carbon-intensity metric recommended by the TCFD (firms’ GHG emissions divided by revenues) can be produced easily for portfolios containing such companies. By contrast, in order to calculate the carbon-intensity of portfolios containing investments in small firms, workarounds and approximations are needed, due to the gaps in the corporate GHG emission data and the constrained revenue databases. As the MNB’s balance sheet contains a large exposure vis-à-vis the

Hungarian SME sector (FGS programme), the central bank measured the carbon-intensity of the corporate portfolios using the sectoral GHG intensity data based on value added found in the Eurostat database. The carbon-intensity of corporate portfolios is thus the weighted average of the GHG intensity of the different corporate sectors and the sectors’ share within the portfolio.

Table 3			
Central bank methodologies in measuring the carbon-intensity of corporate exposures			
	Magyar Nemzeti Bank	Bank of England	Banque de France
Formula	$WACI = \sum_i \frac{s. \text{ market value}_i}{p. \text{ market value}} * s. \text{ GHGint}_{.i}$	$WACI = \sum_i \frac{\text{market value of exposure}_i}{p. \text{ market value}} * \frac{\text{corp. GHG emissions}_i}{\text{corp. income}_i}$	
GHG data	Eurostat (Air Emissions Intensities): sectoral GHG intensity relative to value added	Corporate reports	The BdF did not provide more information on its chosen data sources
<i>Note: s.=sector, p.=portfolio, GHGint.= GHG intensity, corp.=corporate.</i>			

4.1.2. Brown share

Another metric used for analysing transition risks is the share of the portfolios’ carbon-intensive assets (brown share). The TCFD recommends using the Global Industry Classification Standard (GICS) for identifying high carbon-intensity industries. According to the TCFD’s assessment, the energy and utilities sectors (except for water utilities and renewable energy firms) are the most carbon-intensive; therefore, the financial exposure to the companies in them should be assessed. Instead of the GICS classification, the MNB used the NACE Rev. 2 sectoral classification, which largely overlaps with the carbon-intensive sectors in the GICS. The examination of such corporate exposures is of special importance for investors, as the transition to a carbon-neutral economic structure will pose the greatest challenge to high carbon-intensity firms, so those are the riskiest in terms of technology and regulation as well. Out of the corporate exposures on the MNB’s balance sheet, the shares of the carbon-intensive assets in the FGS and BGS portfolios were calculated.

The advantage of the methodology based on sectoral classification is that the analysis does not require complex data, coverage is appropriately transparent and comprehensive, and it also facilitates comparison across asset classes. On the other hand, the drawback of this classification is that even in the most carbon-intensive sectors, there may be firms that strive to achieve carbon-neutrality with new, innovative technologies, and, conversely, highly carbon-intensive companies may operate in low-carbon sectors. In the future, this could be solved by the widespread measurement and transparent communication of corporate GHG emissions, i.e. individual company-level data. Another distortive effect of the NACE Rev. 2-based

sectoral classification may be that renewable energy firms are not separated from traditional businesses using fossil fuels.

Compared to the MNB’s sectoral classification approach, a more focused method was used by the BoE and the BdF. The methodological difference is once again attributable to the different level of detail in reporting and the challenge posed by the availability of data (Table 4). The sectoral analysis may provide an appropriate approximation for investors’ risk exposure, but a more accurate picture can be gained if company’s revenue structure is examined. Companies are not exposed to transition risks because they are classified as belonging to a carbon-intensive sector based, but because a major portion of their revenues come from carbon-intensive activities.²⁹ Thanks to the corporate reports, the BoE and the BdF looked at the percentage of the revenue of the companies in the portfolio related to carbon-intensive activities (production of fossil fuels and energy generation based on that). Besides the above basic metric, the BoE also estimates the portfolio’s risk exposure for a broader group of activities, taking into account the refining and distribution of fossil fuels.

Table 4		
Central bank methodologies in measuring the carbon-intensive assets of corporate exposures		
	Magyar Nemzeti Bank	Bank of England, Banque de France
Formula	$\frac{\text{market value of carbon-int. s.}}{p.\text{market value}}$	$\frac{\text{revenues of carbon-int. activities}}{\text{total corporate revenues}}$
Carbon-intensive activities	Energy and utilities sectors	Fossil fuel production Fossil fuel-based energy production
Sector classification	NACE Rev. 2	N/A
<i>Note: s=sector, p=portfolio, carbon-int.=carbon-intensive.</i>		

4.1.3. Energy mix

To meet the objectives of the Paris Agreement, there must be a major shift in the global energy mix away from burning fossil fuels towards using renewables. One way of measuring the risks arising as a result of this transition process could be the analysis of the energy mix of securities issuers. The methodology helps better assess the exposure of the countries in a given portfolio to the risks related to the establishment of a carbon-neutral energy system. Countries where more substantial changes are needed due to the large share of fossil fuels are obviously

²⁹ The two are basically closely related, and in practice has shown, more and more traditional energy firms venture into the territory of renewables, thereby diversifying their revenue structure and reducing transition risks.

more exposed to transition risks. In its report, the MNB addressed the sovereign exposure of the FX reserves and Hungarian government securities purchases.

The analysis examined the energy mix of the sovereign securities issuers represented in the FX reserves. The energy mix of a sovereign portfolio is the weighted average of the energy mixes of the issuing countries in the portfolio, weighted by their shares in the portfolio. The benchmark used for the analysis was the portfolio represented as IMF COFER,³⁰ and a forward-looking estimate benchmark was used in the form of the Sustainable Development Scenario (SDS) published by the International Energy Agency (IEA). The SDS is an integrated scenario that determines the path leading to reliable, sustainable and modern energy services, contributing to the mitigation of pollutions and effectively combats climate change (IEA 2021).

The MNB's energy mix analysis for sovereign exposures is the same as the one published in the 2020 report of the BoE. In its latest report in 2021, the Bank of England replaced this static analysis based on backward-looking data with a forward-looking method. The new approach looks at the portfolio's so-called warming potential, estimating the heating scenario that is consistent with the future GHG emission path of the sovereigns in the portfolio, and establishing whether or not the portfolio itself meets the 1.5–2°C target of the Paris Climate Accords. The analysis is mostly based on the results of the Climate Action Tracker research project. This independent research project seeks to examine the impact of implemented or planned GHG mitigation measures on the GHG trajectory of the corresponding countries, in order to determine whether the countries can meet international targets. One advantage of the analysis is that it focuses on the future, but it is thus also highly uncertain, as countries have repeatedly backtracked on their commitments and measures in recent decades. The analysis does not cover every country, so it only has limited applicability for diversified portfolios such as the MNB's FX reserves. Similar to the new methodology of the BoE, the BdF uses the warming potential of the portfolios.

4.2. Physical risk

Physical risk means that the change in climatic conditions, such as the rise and variability in average temperatures, or a shift in the amount and distribution of precipitation, including droughts and floods, might affect the value of the financial assets on institutions' balance sheets, in this case the balance sheets of central banks. Assessing physical climate risk exposures involves major technical challenges, requiring detailed geographical data to determine the seriousness of the potential weather events at various locations.

³⁰ The IMF COFER (Currency Composition of Official Foreign Exchange Reserves) represents the currency composition of the world's FX reserves.

Physical risk results show the relative riskiness of entities within the analysis universe. The scores of the risk categories show a percentile ranking, ranging 0–100, where 0 means the lowest level of risk, while 100 denotes the highest exposure. The result of the methodology points out the riskiest areas and entities, potentially requiring further analysis. In the MNB’s first TCFD report, the analysis of physical risks covers a smaller group of financial assets on the MNB’s balance sheet, namely sovereign exposures and Hungarian large enterprise bonds and loans.

The methodology of analysing the physical risk of sovereign and corporate entities is the same in the MNB, the BoE and the BdF, due to the same third-party analysis firm. The only difference can be found in the practical analysis of corporate assets, where the service provider, utilising extensive company information databases, performs a more detailed analysis of global corporations than in the case of smaller firms. The central banks use the data and models of Four Twenty Seven (Moody’s Analytics) in analysing physical risks, with the results of six risk categories taken into account: floods, heat stress, hurricanes and typhoons, sea level rise, water shortage (water stress) and wildfires (*Table 5*). Within the risk categories, a number of indicators are quantified that capture the change in the exposure of the entity (country or company) to physical risks over the forecast horizon (decade to 2030). The scenario used to predict physical risk is based on the GHG trajectory adopted by the IPCC.

Table 5			
Physical risk assessment			
	Magyar Nemzeti Bank	Bank of England	Banque de France
External data provider	Four Twenty Seven (Moody’s Analytics)		
Physical risk categories under review	Floods Heat stress Hurricanes and typhoons Sea level rise Water shortage (water stress) Wildfires		

5. Conclusion

In market-based economies, transparency is of the essence, because without the transparent operation of individual economic entities, resource allocation cannot be efficient. Until now, the transparency requirement was typically interpreted in the dimension of risk, return and liquidity, but the green transition of the economy means that the transparency and availability of environmental sustainability considerations is becoming more important.

One precondition for the successful green transition of the economy is that financial markets take into account and appropriately assess exposure to climate risks. Investors and markets need to be able to analyse and assess sustainability considerations, and climate risk exposure needs to be included in risk models, return expectations and the pricing of financial products, which can be achieved through transparency.

Transparency rests on data, the evaluation and analysis of which requires an appropriate methodology. There are major challenges in green considerations in terms of the content, homogeneity and comparability of data as well as the methodologies and models used. While the traditional securities market offers decades of data and experience, green markets are only 5–10 years old, and they are also tiny compared to the entire securities market. Regulation should solidify on the market, best practices should emerge in disclosure and models, and data transparency should meet the demands of investors, and this all takes time.

The development of green markets and transparency also requires the appropriate attitude of regulators and central banks. Central banks have already committed themselves to transparency related to climate risk exposures, although for now only a few central banks publish their forward-looking climate risk exposure in line with TCFD recommendations. Independent reports were only prepared, or are being prepared, by the Bank of England, the Banque de France and the Magyar Nemzeti Bank. Besides climate-related financial disclosure, the macroprudential and microprudential measures as well as the monetary policy instruments in certain countries, such as Hungary, and asset purchase programmes also increasingly respond to climate risks (*NB 2021d*), which reflects the onset of a ‘green turnaround’ in the world of central banking.

This paper described the climate risk exposure analysis of financial assets, including the currently identifiable major challenges as well as the practical solutions of the central banks that have already started reporting. Widespread reporting by economic actors³¹ requires that uniform rules, definitions and enforceable requirements related to environmental exposure soon be established.³² This can be promoted by central banks in line with their statutory mandate, by developing their own transparency and establishing the methodological framework for reporting.

³¹ Of course, this will also require a change in accounting practices. For more on this, see: *O’Dwyer – Unerman (2020)*.

³² It should be noted here that reporting has already started on a voluntary (market) basis, see: *Eccles – Krzus (2018)*.

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