

Forest carbon and a regional perspective on the effectiveness of financial instruments within the forest bioeconomy

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Abstract: The forest bioeconomy links to a climate-neutral economy for which effective economic and financial promotion is essential to sustainable development. The main purpose of this study was to examine the effects of financial support on the development of the forest bioeconomy in the Czech Republic in the period 2000–2021. Research objectives were met by applying literature review, time series analysis, spatial data analysis, cartogram and cartodiagram method, correlation analysis, and regression analysis. Firstly, regional divergences in financial flows were observed. Owing to the bark beetle calamity, the peak of the financial support was detected in the Vysočina Region (CZK 4 658/EUR 190 per ha), and the Olomouc Region (CZK 2 780/EUR 113 per ha) in 2020. An upward trend – more than 6-fold growth of financial flows to forestry was found. Secondly, the forest carbon model was discovered and tested. Financial contribution for reforestation, establishment, and tending of forest stands increases net carbon sinks while financial contribution for green and environmentally friendly technologies increases net carbon sources. Regional carbon reservoirs offer the potential to contribute to climate targets and achieve sustainable progress.

Keywords: circular economy; Czech Republic; financial support; forestry; regional analysis; spatial analysis

Environmental changes worldwide are speeding up and constitute considerable threats to society. Currently, the carbon neutrality of the European Union by 2050 (European Commission 2019), compliant with the ambitions of the Paris Agreement (UN 2016), is a global challenge and would require a long-term engagement, predominantly at the regional scene. Global greenhouse gas (GHG) emissions (IPCC 2023) result from an unsustainable approach in energy usage, land use, and land-use change, consumption and/or production

behaviour across regions and national economies. The study by Rae et al. (2021) refers reconstruction of carbon dioxide emissions over the past 66 million years. The long-term growing GHG concentration reached an all-time peak of 420 parts per million in 2021 (Scripps Institution of Oceanography 2023). The amplifying feedbacks deflect the climate system in the same direction as the initial disturbance (Cramer et al. 2018). Global warming delivers negative repercussions in the form of extreme weather events, especially droughts,

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windthrows, heatwaves, etc. (Scinocca et al. 2016; Thrippleton et al. 2023). Finally, the carbon budget (Matthews et al. 2017) is a promising method for setting out the challenge of climate change mitigation.

The carbon cycle explains the flow of carbon into and out of the atmosphere and into living organisms (Porfirio et al. 2010). A cumulative effect displays net sources escalating carbon levels and concentration, due to a linear economy system (Tyson et al. 2001; Wesche, Armitage 2014). Anthropogenic carbon sources, such as burning fossil fuels and deforestation, have been increasing since the pre-industrial era (Ford et al. 2012). On the contrary, forests tend to be net carbon sinks (Keeling et al. 2011; FISE 2023). However, forests can become a net carbon source due to unsustainable management (European Commission 2023). Studies centred on forest carbon in specific regions were identified, such as Liski et al. (2002), Miller et al. (2012), Zald et al. (2016), Karppinen et al. (2018), and Moser et al. (2022).

In each region, forests have different environmental features, states, biodiversity, and challenges in addressing climate change (UN Department of Economic and Social Affairs, and UN Forum on Forests Secretariat 2021). Simultaneously, regions and their biogeographical characteristics are not stagnant throughout time. Because of climate change, adaptive management decisions could be made (Zimmermannová 2009; Allen et al. 2010; CENIA 2022). A range of closer-to-nature approaches are already in use, such as natural regeneration, leaving deadwood, and abandoning the use of pesticides (Hlásny et al. 2017). However, the philosophies are diverse from region to region (Larsen et al. 2022). Moreover, ongoing climate change is placing pressure on building the forest's ability to flourish in the face of current and changing conditions, enhancing its resilience while storing carbon in trees as well as in the forest soils (IUFRO 2014a).

Efforts at both regional and global scales are needed while synergies between climatic, forest-based, and societal policies will streamline the process (Nabuurs et al. 2017; Bowditch et al. 2022). The shift from fossil fuels to bioenergy or from carbon-intensive materials to biomass tends to mitigate climate change (IUFRO 2014b). This requires the development of four key domains (Rockström et al. 2017), such as investment, innovation, institutions, and infrastructure.

An integral component of sustainable development includes the bioeconomy concept at the European Union level (European Commission 2018b). Bioeconomy is primarily rooted in the traditional sectors of the economy, namely agriculture, forestry, aquaculture, and the production of paper and wood-related goods. Nonetheless, innovative sectors are also included, namely bioenergy, biofuels, biotextiles, and biochemicals while their significance is strengthening over time (Ronzon et al. 2017). The study presented by Ronzon et al. (2015) segregates the national economies under (i) agricultural bioeconomies, (ii) agro-food industry and bio-based chemical industries, (iii) forest bioeconomies, and (iv) non-specialised bioeconomies.

Currently, the forest bioeconomy is gaining prominence and is part of a comprehensive set referred to as the 'Fit for 55' package, a toolbox of proposed revisions and new initiatives to ensure that EU policies are aligned with climate targets (European Commission 2021c). In detail, the New EU Forest Strategy (European Commission 2021b) focuses on the cascading principle of biomass usage, forest restoration, financial support for forest owners and rural areas, and protection of forest ecosystems. Alongside the environmental benefits of carbon capture and storage, multifunctional forests fulfil a countless array of ecosystem services, such as climate regulation, water control, soil protection, wildlife, recreation, etc. (Börner et al. 2017; Masiero et al. 2018; Winkel et al. 2022). Frequently, such advantages are delivered as public goods and externalities (Šišák 2006) while the total economic value indicator attempts to reflect the aggregate quantification of beneficiaries (Merlo, Croitoru 2005). Topically, forest bathing of *shinrin-yoku*, as a mindful visit to the forest, improves human physical and mental health and prevents the development of various diseases (Mao et al. 2012; Putra et al. 2018; Wen et al. 2019; Antonelli et al. 2022; Farkic et al. 2021).

The Czech Republic and its regions are part of the European temperate forest zone (Rivas-Martínez et al. 2004). Forests cover 37% of the territory, approximately 2.68 million ha in 2022 (CZSO 2023). Considering the ownership structure, 54% is owned by the state, 21% by individuals, 16% by municipalities, and 9% by other owners. In addition, 74.1% of Czech forest land is classified as management forests, while 23.9% as special purpose forests and 2.1% as protective forests. The tree species compo-

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sition contains a significant proportion of spruce (48.1%), pine (16%), beech (9.3%), and oak (7.6%). The Czech Republic clusters into the non-specialised bioeconomy (Ronzon et al. 2015). However, social (Hájek et al. 2021; Perunová, Zimmermannová 2022) and economic aspects (Perunová, Zimmermannová 2023) of the forest bioeconomy can be seen. Additionally, the national financial support mechanism for forestry is imprecise, and administratively intensive, which reduces the effectiveness of financial flows for forest owners in the Czech Republic (MoA 2020).

Typically, the Czech Republic is struggling with the unprecedented negative consequences of the bark beetle calamity (MoA 2022), rated to be the most devastating in history (Brázdil et al. 2022). A switch from wind-driven to drought-driven outbreak dynamics was observed (Hlásny et al. 2021). For example, the study by Šafařík et al. (2022) provides insight into raw wood growing stocks and forecasts further cuttings according to coniferous stands in the Czech Republic. Secondly, Michalec et al. (2020) analysed the sale of bark beetle-affected sawmill timber. Finally, Toth et al. (2020) display the relationship linking the incidental harvest volume and the drop in the price of spruce timber. Additionally, since 2015, there have been continuous increases in several indicators, such as the total volume of trees killed by bark beetles, and the total volume of salvage logging (MoA 2022; CZSO 2023). These are the principal drivers of the land use, land-use change and forestry (LULUCF) sector emissions balance (IPCC 2023), which have caused negative environmental effects. For this, forest restoration is one of the current regional challenges in the Czech Republic (MoA 2019).

The literature review identified a range of studies dealing with national funding for forestry in the Czech Republic, for instance, Šišák (2002, 2007, 2013), Kotecký (2015), Lojda and Ventrubová (2015), and Perunová and Zimmermannová (2022). The mentioned studies tracked national financial sources and/or other financial and economic instruments at the national level, with no consideration of regional differences. Simultaneously, the studies, such as Michalec et al. (2020), Toth et al. (2020), Hlásny et al. (2021), Brázdil et al. (2022), and Šafařík et al. (2022), examined bark beetle calamity in the Czech Republic, with no regard to regional disparities in financial support. To sum up, studies investigating regional aspects of the national finan-

cial sources and/or studies dealing with the economic aspects of bark beetle calamity emphasising regional differences in the Czech Republic are still absent. This study tries to fill this gap.

MATERIAL AND METHODS

Material. Financial support is represented by financial contributions for forest management provided by the budget of the Ministry of Agriculture. The data utilised are not commonly available and are accessible upon request. From the extensive datasets received, selected data were extracted and harmonised for the given monitored period.

Other data originated from public databases, including the Eurostat (Eurostat 2023), the Czech Statistical Office (CZSO 2023), and the United Nations Framework Convention on Climate Change (UNFCCC 2023). All figures have been converted according to the EUR/CZK exchange rate applicable on December 17, 2023 (ČNB 2023).

To determine the impact of different national funding titles on forest carbon storage, data were collected for the period 2000–2021. The data sources were the CZSO (2023), the UNFCCC database (2023), and the Ministry of Agriculture (data upon request).

The presented model operates with GHG emissions/removals of selected sub-categories of the LULUCF sector, namely forest land and harvested wood products.

The independent variables depict the financial support implemented in the bioeconomy sector in the Czech Republic, such as financial contribution to the restoration of forests damaged by immission, financial contribution for reforestation, establishment, and tending of forest stands, financial contribution to an association of owners of small forest areas, financial contribution for green and environmentally friendly technologies, financial contribution for the elaboration of forest management plans, financial contribution for forest protection, financial contribution to mitigating the impact of the bark beetle calamity (Table 1).

The expected impact of all financial contributions is positive (Table 2). Such expectation is assumed by Jinggang and Peichen (2017), Lee et al. (2018), Pukkala (2020), Bowditch et al. (2022), and He and Ren (2023).

Forest carbon (Figure 1) displays a negative range between 1990–2017, which stands for the net sink,

Table 1. List of variables

Variable	Abbreviation	Unit	Role
Forest carbon	<i>FORC</i>	tonnes of carbon dioxide equivalent (tCO ₂ eq.)	dependent
Financial contribution to the restoration of forests damaged by immission	<i>A</i>	million CZK	independent
Financial contributions for reforestation, establishment, and tending of forest stands	<i>B</i>	million CZK	independent
Financial contributions to an association of owners of small forest areas	<i>C</i>	million CZK	independent
Financial contributions for green and environmentally friendly technologies	<i>D</i>	million CZK	independent
Financial contributions for the elaboration of forest management plans	<i>H</i>	million CZK	independent
Financial contributions for forest protection	<i>I</i>	million CZK	independent
Financial contributions to mitigate the impact of the bark beetle calamity	<i>L</i>	million CZK	independent
Time	<i>TIME</i>	years	control

Source: Authors' own processing

and carbon capture and storage in forests and harvested wood products (HWPs) is observed. The reverse tendency shows the timeframe 2018–2021, positive figures denote a net source boosting total GHG emissions.

Table 3 collects the parameters of all variables. The minimum and maximum values, standard deviation, and median are given for each variable.

Methods. The main purpose of the study was to examine the effects of financial support on the development of the forest bioeconomy in the Czech Republic in the period 2000–2021. With regard

to the main target of the research, the following research questions were established:

The first research question deals with the development of selected financial support (RQ1): Can we observe an increasing trend in the amount of financial flows to forestry in the Czech Republic?

The second research question observes the regional aspect in the forest bioeconomy development (RQ2): Can we observe regional differences in the amount of financial flows to forestry in the Czech Republic?

The third research question focuses on the environmental aspect of the forest bioecon-

Table 2. Expected impact of variables in FORCM

Variable	Abbreviation	Expected impact FORCM
Financial contribution to the restoration of forests damaged by immission	<i>A</i>	positive
Financial contribution for reforestation, establishment, and tending of forest stands	<i>B</i>	positive
Financial contribution to an association of owners of small forest areas	<i>C</i>	positive
Financial contribution for green and environmentally friendly technologies	<i>D</i>	positive
Financial contribution for the elaboration of forest management plans	<i>H</i>	positive
Financial contribution for forest protection	<i>I</i>	positive
Financial contribution to mitigate the impact of the bark beetle calamity	<i>L</i>	positive
Time	<i>TIME</i>	positive

FORCM – model containing all financial contributions

Source: Authors' own processing

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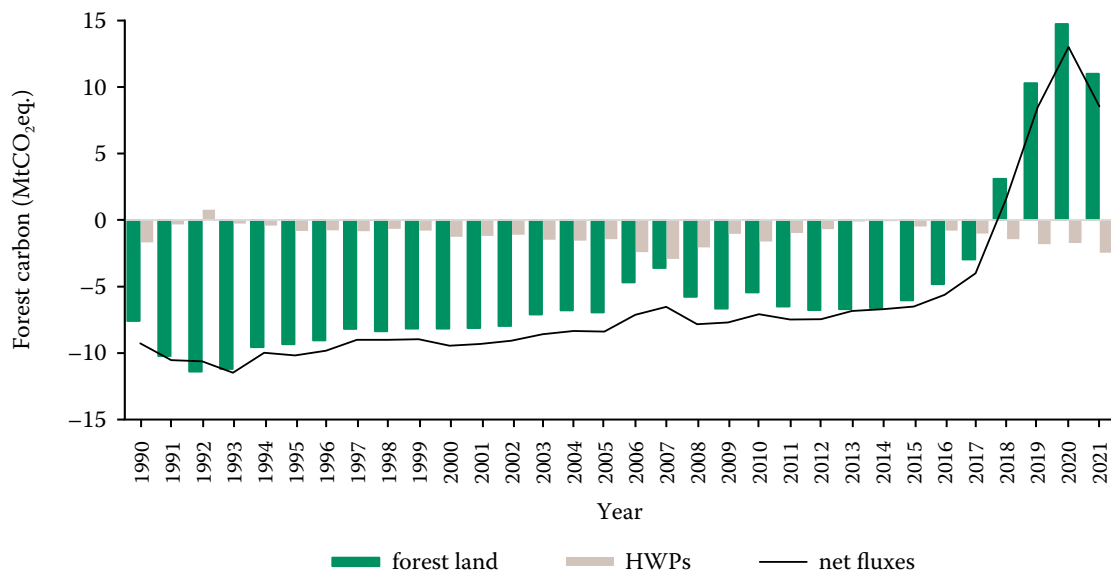


Figure 1. Development of the greenhouse gas emissions/removals of selected sub-categories of the LULUCF sector
LULUCF – land use, land-use change and forestry; MtCO₂eq. – megatonnes of carbon dioxide equivalent; HWPs – harvested wood products
Source: Authors' own processing, based on UNFCCC (2023)

omy development (RQ3): Do financial flows have a positive environmental impact in the Czech Republic?

In order to meet the research objectives, a literature review, time series analysis, spatial data analysis, cartogram and cartodiagram meth-

Table 3. Overview of the data statistics

Abbreviation	Variable	Minimum	Maximum	Standard deviation	Median
<i>FORC</i>	forest carbon	−9 462 330.399	12 719 417.070	6 358 628.517	−7 180 636.361
<i>A</i>	financial contribution to the restoration of forests damaged by immission	2 206 000.000	28 415 000.000	7 949 890.483	12 668 663.780
<i>B</i>	financial contribution for reforestation, establishment, and tending of forest stands	100 621 043.400	1 405 096 249.000	287 694 414.300	222 662 500.000
<i>C</i>	financial contribution to the association of owners of small forest areas	1 263 000.000	4 033 000.000	1 143 315.689	2 761 000.000
<i>D</i>	financial contribution for green and environmentally friendly technologies	14 250 217.220	180 785 676.000	46 290 996.610	24 769 000.000
<i>H</i>	financial contribution for the elaboration of forest management plans	1 900 000.000	82 300 000.000	25 318 568.870	29 564 735.000
<i>I</i>	financial contribution for forest protection	1 154 956.852	116 321 104.000	33 015 060.200	3 150 000.000
<i>L</i>	financial contribution to mitigate the impact of the bark beetle calamity	979 862 761.100	7 027 364 513.000	3 051 191 672.000	3 296 433 478.000

Source: Authors' own processing

od, correlation analysis, and regression analysis were applied.

Firstly, a comprehensive literature review and data collection were carried out. Data and time series were modified into a format suitable for Excel.

Secondly, quantitative analysis was performed, specifically time series analysis, spatial data analysis, the cartogram and cartodiagram method, correlation analysis, and regression analysis. The data and time series were analysed together with their characteristics. Spatial data analysis was performed using the QGIS software (Version 2.26.3, 2022). The 'Boundaries' layer from the Data200 topographic database of the Czech Republic (Geoportál ČÚZK 2019) served as a topographic base. To demonstrate regional differences in the allocation of financial support, a regional analysis approach was used, especially the nomenclature of territorial units for statistics – NUTS level 3 (NUTS3) was applied. The list of the regions in the Czech Republic is included in Table 4.

A correlation analysis using Pearson's correlation coefficient was employed. Hence, a more complex regression analysis was developed and tested, see Equation (1):

$$\begin{aligned} \text{FORC} = & \beta_0 + \beta_1 \times A + \beta_2 \times B + \beta_3 \times C + \\ & + \beta_4 \times D + \beta_5 \times H + \beta_6 \times I + \beta_7 \times L + \\ & + \beta_8 \times \text{TIME} + u \end{aligned} \quad (1)$$

where:

FORC – forest carbon, in total, in tonnes of carbon dioxide equivalent (tCO₂eq.);

A – financial contribution to the restoration of forests damaged by immission;

B – financial contribution for reforestation, establishment, and tending of forest stands;

C – financial contribution to an association of owners of small forest areas;

D – financial contribution for green and environmentally friendly technologies;

H – financial contribution for the elaboration of forest management plans;

I – financial contribution for forest protection;

L – financial contribution to mitigate the impact of the bark beetle calamity;

TIME – time;

u – random element of the model.

First, the model containing all financial contributions (FORCM) was developed. FORCM is the com-

Table 4. Overview of the regions of the Czech Republic

NUTS3	Name	Abbreviation
CZ010	Prague, the Capital City	PRG
CZ020	Central Bohemian Region	CBR
CZ031	South Bohemian Region	SBR
CZ032	Plzeň Region	PLR
CZ041	Karlovy Vary Region	KVR
CZ042	Ústí nad Labem Region	ULR
CZ051	Liberec Region	LBR
CZ052	Hradec Králové Region	HKR
CZ053	Pardubice Region	PAR
CZ063	Vysočina Region	VYR
CZ064	South Moravian Region	SMR
CZ071	Olomouc Region	OLR
CZ072	Zlín Region	ZLR
CZ080	Moravian-Silesian Region	MSR

NUTS – nomenclature of territorial units for statistics

Source: Authors' own processing, based on Eurostat (2023)

position of all independent variables (*A*, *B*, *C*, *D*, *H*, *I*, *L*, and *TIME*). Second, alternative models were performed to identify the statistically most significant model with a high index of determination.

Finally, all outputs were validated via multiple tests. The *F*-test of overall significance investigated the adequacy of the regression models. The Durbin–Watson (*DW*) test was conducted to test autocorrelation employing Durbin–Watson Significance Tables (Evans 2023).

RESULTS

Tendency in the financial support. Figure 2 displays the development of the amount and structure of financial flows to forestry in the Czech Republic in 2000–2021.

Based on the 2000–2009 results, the total financial support fluctuated from CZK 300 to 380 million (from EUR 12.23 to 15.49 million). Since 2008, there has been a downward trend caused by the economic crisis and the decline in economic activity. In addition, several subjects were transferred under regional budgets, which restricted financial support for forestry since 2005. In 2010–2016, the mean financial flows stood at CZK 185 million (EUR 7.54 million). Because of the bark beetle calamity, financial support increased in the period 2017–2021. An all-time maximum of CZK 1 715 million (EUR 70 million) was record-

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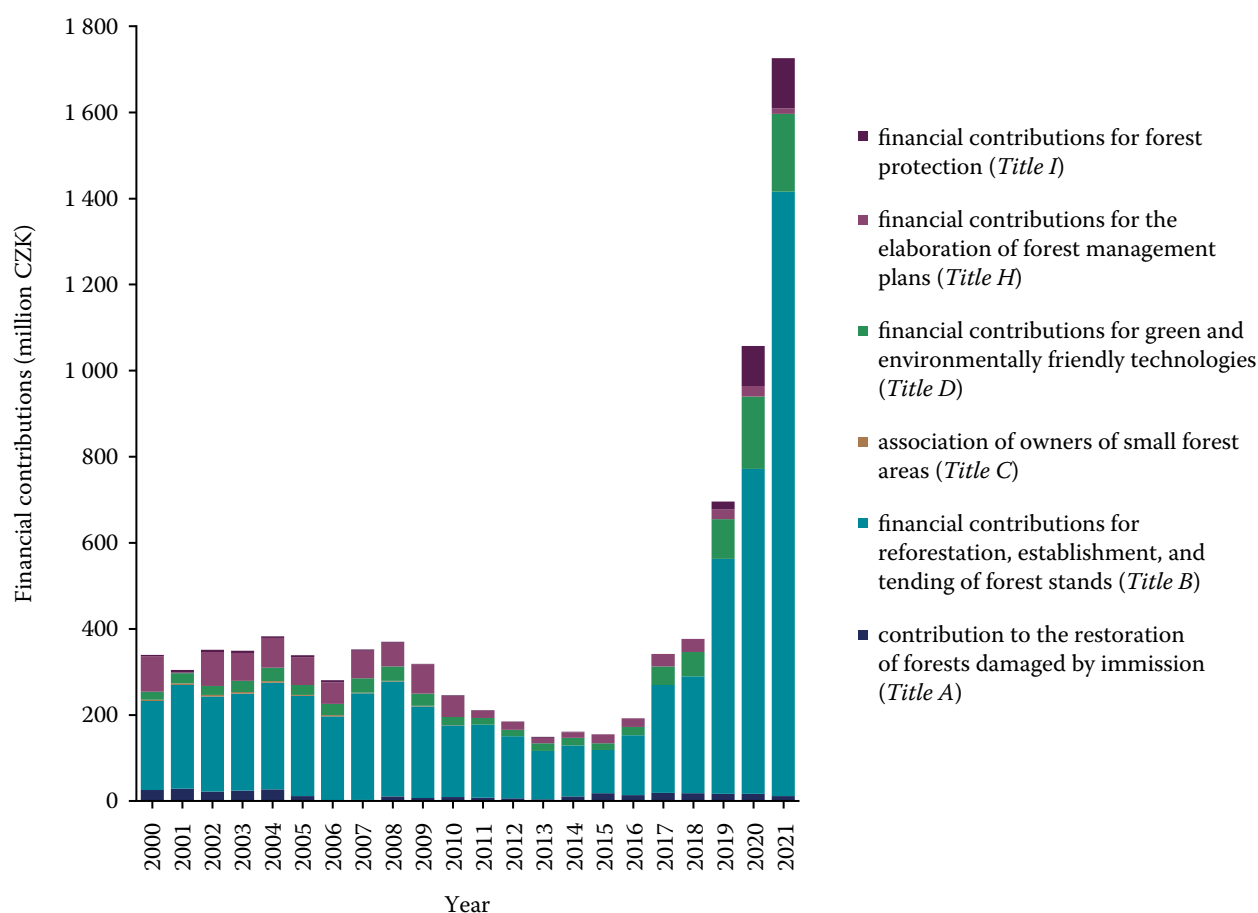


Figure 2. Development of the amount and structure of financial contributions for forestry granted from the budget of the Ministry of Agriculture

Source: Authors' own processing, based on data provided by the Ministry of Agriculture of the Czech Republic

ed in 2021. According to the structure, *Title B* represented the highest share (61–81%) each year. Comparing the beginning and the end of the monitoring interval, two tendencies are visible, namely a downtrend for *Title A*, *Title C*, and *Title H* and an uptrend for *Title B*, *Title D*, and *Title I*.

In regional detail, 75% of *Title A* volume was consumed by the Ústí nad Labem Region (ULR), followed by the Karlovy Vary Region (KVR) and the Hradec Králové Region (HKR). In each region, *Title B* constitutes the highest share of the total national financial support. Nine regions benefited from *Title C*, the most recent of which was Vysočina Region (VYR) in 2010. *Title D* was covered by regional budgets and fell in the period 2005–2012. Moreover, in 2009–2010, the Central Bohemia Region (CBR), the Ústí nad Labem Region (ULR), and the Moravian-Silesian Region (MSR) abolished it. On the contrary, the Vysočina Region (VYR) exhibits a growing trend.

In the period 2013–2016, the subjects of *Title D* moved under the Governmental Regulation No. 30/2014; in 2017 the figures increased sharply, and in 2021 achieved the maximum level in the period under review. The development of *Title H* was influenced by several factors, such as the reduction of the rate to CZK 300/EUR 12.23 per ha between 2007–2008 or the introduction of the *de minimis* regime, which caused a 2.5-fold decrease between 2010–2011. A declining number of supported subjects of *Title I* was observed, and since 2015 has not been included. The 2019–2021 uptake is related to bark beetle disturbance.

To summarise, a bark beetle calamity occurred in the Czech Republic, which led to significant changes in the financial flows. The financial contribution to mitigate the impact of the bark beetle calamity (*Title L*) was introduced and covered 58% (2019), 87% (2020), and 66% (2021) of total financial support in forestry. For clarity, regional diver-

gences have been examined for *Title A – Title I* and separately for *Title L* in the following subchapters.

Regional differences in financial support (*Title A – Title I*). An increase in financial support flowing to forestry in 2000–2021 was found. Nevertheless, the financial flows were not equally allocated across regions. For this, the indicator of the financial contributions for forestry granted from the budget of the Ministry of Agriculture (*Title A – Title I*) per ha was set to detect regional divergences. Figure 3 presents regional differences in financial contributions for forestry granted from the budget of the Ministry of Agriculture (*Title A – Title I*) per ha.

Based on the findings in 2009, the highest financial contributions per ha were received in the Central Bohemian Region (CBR) CZK 177/EUR 7.22 per ha, and the Pardubice Region (PAR) CZK 165/EUR 6.73 per ha. From 2010 to 2016, a fall in indicator was displayed in each region. Since 2017, the indicator continuously escalated across the regions and reached a historical level in the Vysočina Region (VYR) of CZK 1 528/EUR 62 per ha in 2021. In the reference period, the average national financial flows, *Title A – Title I* per ha, were up approximately 4.5-fold.

Regional differences in financial support (*Title L*). In the monitoring period, a bark beetle calamity occurred in the Czech Republic, which led to significant changes in the financial flows to the forestry sector. Figure 4 demonstrates that in 2019 the financial contribution to mitigate the impact of the bark beetle calamity (*Title L*) covered 58% of the national financial sources, which amounted to CZK 979.86 million (EUR 40 million). In the following year, the share of *Title L* rose to a peak of 87% (CZK 7 027.36 million/EUR 286 million) of the national financial sources. In 2021, *Title L* delivered CZK 3 296.43 million (EUR 134 million), approximately 66% of the national financial sources. Generally, there was a historical peak of the financial contributions for forest management granted from the budget of the Ministry of Agriculture (national financial sources) in 2020.

The indicator of the financial contribution to mitigate the impact of the bark beetle calamity (*Title L*) per ha was set to detect regional divergences. In Figure 5, regional differences in the financial contribution to mitigate the impact of the bark beetle calamity (*Title L*) per ha are illustrated.

Regarding 2019, the peak of indicator emerged in the Zlín Region (ZLR), and the Olomouc Region

(OLR). This year, the Karlovy Vary Region (KVR) and Prague, the Capital City (PRG), were not applying. In 2020, a historical outlier of CZK 4 658/EUR 190 per ha was documented in the Vysočina Region (VYR). Regions with an indicator on the scale of CZK 1 000–2 000 per ha formed the most numerous category. The Vysočina Region (VYR) and the South Bohemian Region (SBR) achieved the strongest support in 2021.

To sum up the period 2019–2021, the accumulated flows of *Title L* per ha in maximum were observed in the Vysočina Region (VYR), the Olomouc Region (OLR), and the Zlín Region (ZLR). Indeed, the peak of both indicators, such as the sum of *Title A – Title I* per ha and *Title L* per ha, were granted in 2020 to the Vysočina Region (VYR), comprising 85% of *Title L*, 10% of *Title B*, and 4% of *Title D*.

Forest carbon model. Figure 1 deals with GHG emissions/removals of selected sub-categories of the LULUCF sector, namely forest land and harvested wood products (HWP). Environmentally, forestry remains a net source of GHG emissions as of 2018. The major contributor is the forest land subcategory (10.997 MtCO₂eq.), a consequence of the bark beetle calamity starting in 2015 and peaking in 2020. During such a period, random harvesting and clear-cutting dominated and the total volume of timber extracted rose rapidly. The Vysočina Region, Olomouc Region, and Moravian-Silesian Region lost the largest percentage of forest stands. Therefore, forest land was the fifth most impactful GHG emissions source in 2021. Forest ecosystems thereby contribute 6.59% to the Czech total GHG emissions as a result of inappropriate management without close-to-nature elements, drought, global warming, loss of resilience, and bark beetle disturbance. The HWP subcategory remains a GHG sink (–2.456 MtCO₂eq.) and decreasing total LULUCF sector emissions (8.358 MtCO₂eq.).

Secondly, all the selected variables that were deemed to influence forest carbon were sampled for correlation analysis, with Table 5 showing its outcome. Based on the results of the correlation analysis, we noticed a statistically significant negative correlation between *FORC* and *C*. In addition to the above correlations, there are also negative correlations with lower statistical significance, such as *A* and *H*. Statistically significant positive correlations occur for *B*, *D*, *I*, *L*, and the control variable *TIME*.

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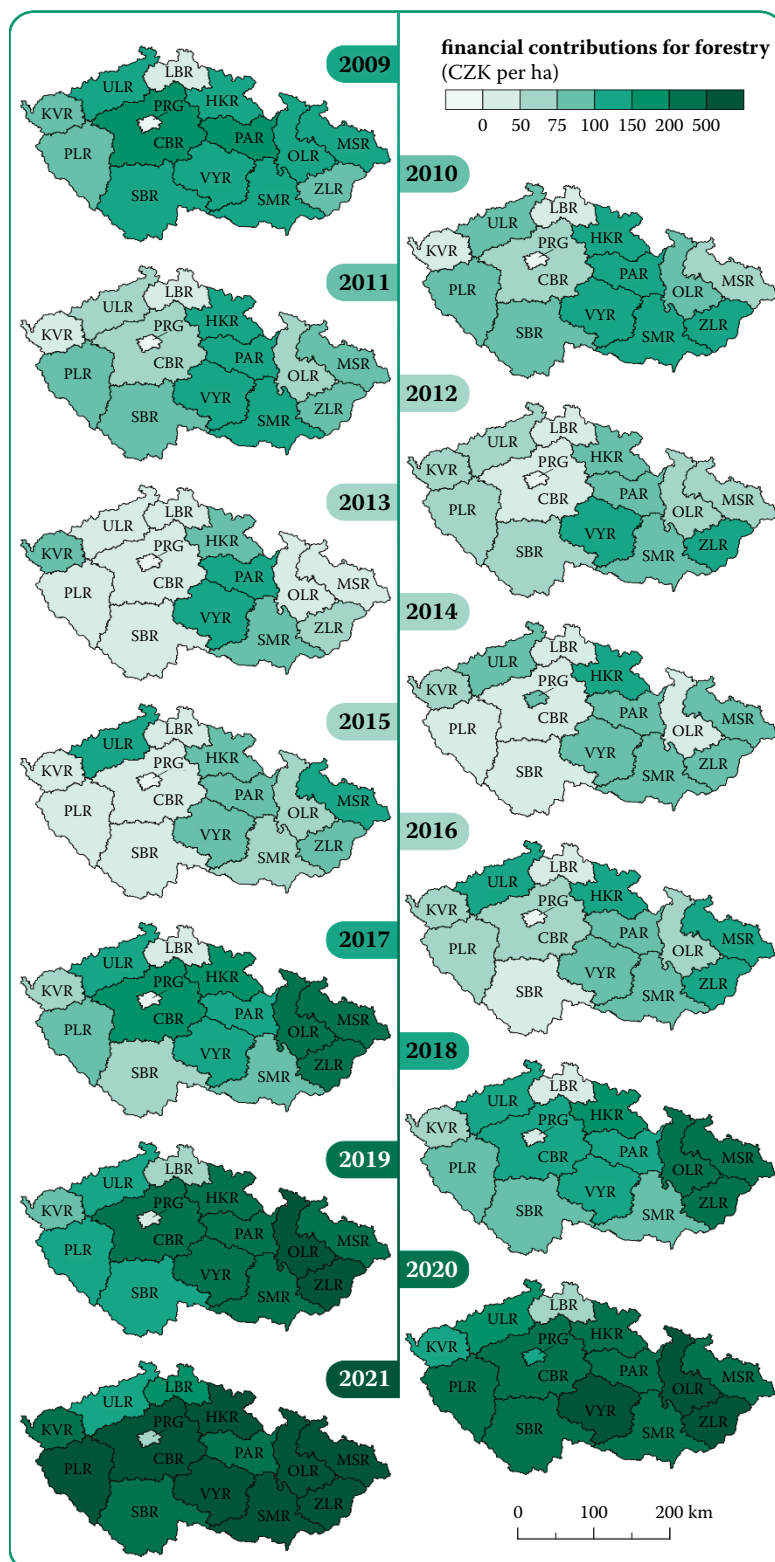


Figure 3. Regional differences in financial contributions for forestry granted from the budget of the Ministry of Agriculture (*Title A – Title I*) per ha

Source: Authors' own processing, based on data provided by the Ministry of Agriculture of the Czech Republic

For regression analysis, the regression model FORCM was developed. FORCM consists of all independent variables (*A, B, C, D, H, I, L, and TIME*). While the entire model is statistically significant,

not all of the selected variables are statistically significant. The result of the Durbin–Watson test (*DW*) for FORCM is acceptable (*DW* 1.861 > upper critical value 0.863).

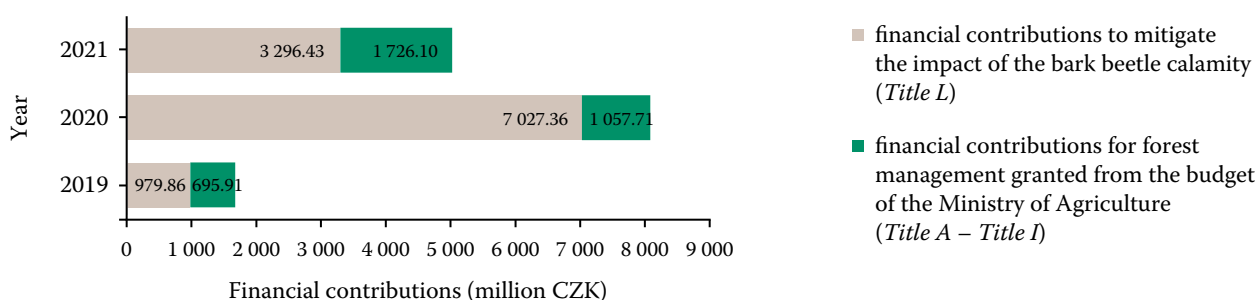
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Figure 4. Financial contributions for forestry granted from the budget of the Ministry of Agriculture (Title A – Title L) in total in 2019–2021

Source: Authors' own processing, based on data provided by the Ministry of Agriculture of the Czech Republic

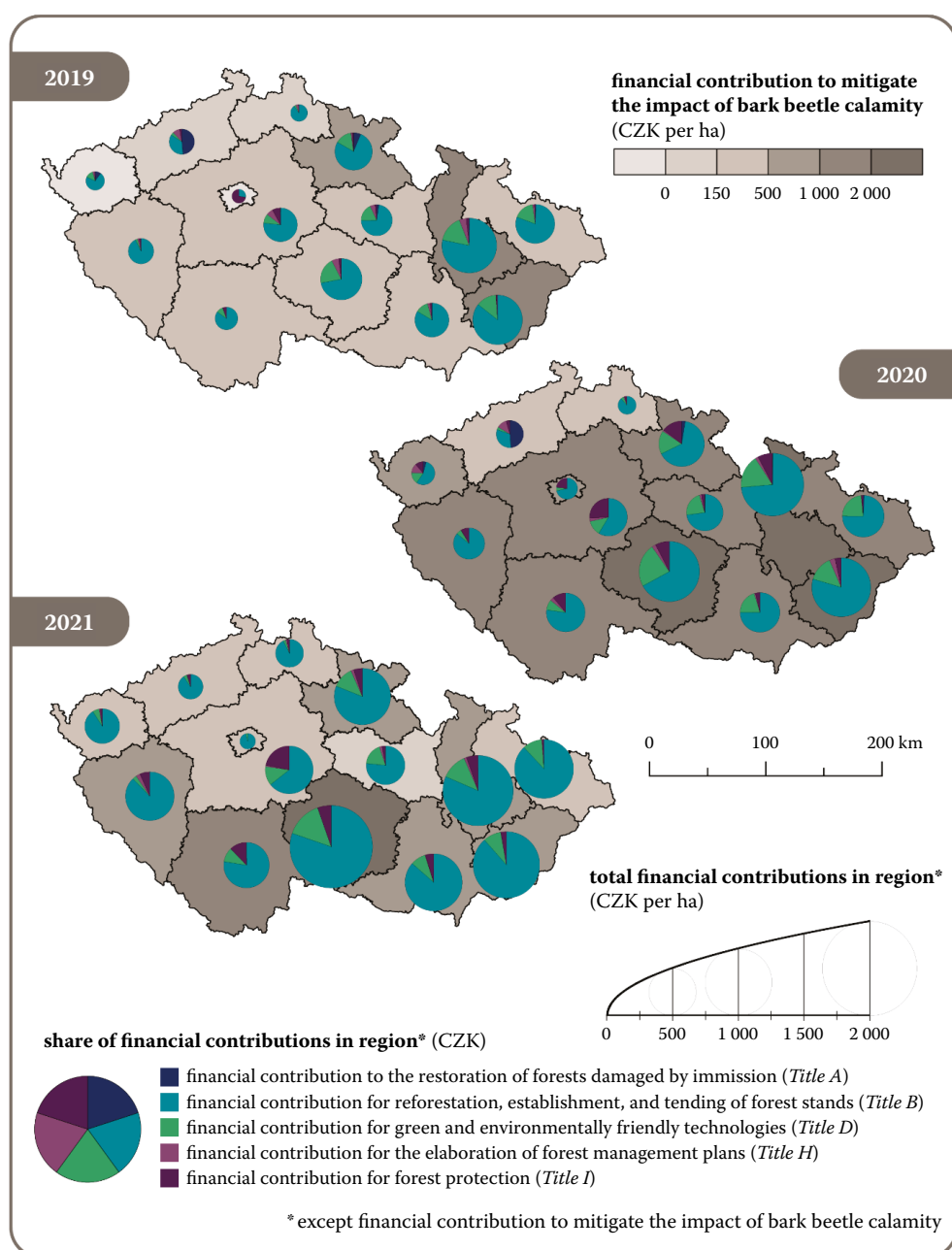


Figure 5. Regional differences in financial contribution to mitigate the impact of bark beetle calamity (Title L) per ha and share of financial contributions (Title A – Title I)

Source: Authors' own processing, based on data provided by the Ministry of Agriculture of the Czech Republic

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Table 5. FORCM – Correlation analysis

Variable	<i>FORC</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>H</i>	<i>I</i>	<i>L</i>	<i>TIME</i>
<i>FORC</i>	1	–	–	–	–	–	–	–	–
<i>A</i>	–0.0039	1	–	–	–	–	–	–	–
<i>B</i>	0.7903	0.0371	1	–	–	–	–	–	–
<i>C</i>	–0.7597	0.8328	0.0841	1	–	–	–	–	–
<i>D</i>	0.9269	0.0449	0.9404	–0.3411	1	–	–	–	–
<i>H</i>	–0.3940	0.1620	–0.2192	0.0097	–0.2714	1	–	–	–
<i>I</i>	0.8486	0.0391	0.9470	0.7308	0.9656	–0.3471	1	–	–
<i>L</i>	0.9373	0.1677	0.1009	0.0000	0.7047	0.2287	0.6337	1	–
<i>TIME</i>	0.7665	–0.2918	0.4773	–0.8737	0.6043	–0.6591	0.6594	0.3796	1

FORCM – model containing all financial contributions; *FORC* – forest carbon; *A–L*, *TIME* – see Table 1 for details

Source: Authors' own processing

Forest carbon model 1 (FORCM1) represents selected variables with a statistical significance of $P < 0.05$. This model is statistically significant – all of the variables are statistically significant, and the entire model is statistically significant as well. In Table 6, the outcomes imply a high coefficient of determination in the model. This means that for FORCM1, the general formula that is specified explains more than 99% of the variance with less than 5% of random deviations. Variables with a P -value of below 5% are *B*, *D*, *TIME*, and the constant (FORCM1). To the results of the overall F -test, the estimated regression forest carbon model is sta-

tistically significant at 5% (FORCM1) levels of significance. The finding of the Durbin–Watson test (DW) for FORCM1 shows positive autocorrelation, and DW is under the lower critical value.

According to the FORCM1 outputs (Table 6), a statistically significant negative relationship between *FORC* and *B* and a statistically significant positive relationship between *FORC* and *D*, and *TIME* is observed. FORCM1 refers to a model that simultaneously involves all three independent variables, namely *B*, *D*, and *TIME*. If separately (correlation analysis), the impact on forest carbon is positive, independent variables *B* and *D* both con-

Table 6. FORCM – Regression analysis

Parameter	FORCM		FORCM1	
	significance	coefficient	significance	coefficient
<i>A</i>	0.506	0.033	–	–
<i>B</i>	0.013	–0.011	0.006	–0.011
<i>C</i>	–	–	–	–
<i>D</i>	0.000	0.166	0.000	0.172
<i>H</i>	0.907	0.002	–	–
<i>I</i>	–	–	–	–
<i>L</i>	–	–	–	–
<i>TIME</i>	0.015	277 814.887	0.002	247 637.603
Constant	0.014	–567 715 072.752	0.001	–506 566 127.350
Observations	22.000	–	22.000	–
R^2	0.977	–	0.976	–
Significance F	0.000	–	0.000	–
Durbin–Watson test	1.861	–	1.803	–

FORCM – model containing all financial contributions; FORCM1 – forest carbon model 1; *A–L*, *TIME* – see Table 1 for details; R^2 – multiple correlation of determination

Source: Authors' own processing

tribute to increasing GHG emissions to the atmosphere. In the complex regression model (FORCM1), the reverse effect of the independent variable B is noted, suggesting a contribution to an increase in GHG removals from the atmosphere.

The following regression Equation (2) can be built:

$$\text{FORC} = -506\,566\,127.350 - 0.011 \times B + 0.172 \times D + 247\,637.603 \times \text{TIME} + u \quad (2)$$

where:

FORC – forest carbon, in total, in tonnes of carbon dioxide equivalent (tCO₂eq.);

B – financial contribution for reforestation, establishment, and tending of forest stands;

D – financial contribution for green and environmentally friendly technologies;

TIME – time;

u – random element of the model.

Based on the regression analysis results, independent variable B (CZK million) contributes to increasing GHG removals from the atmosphere. According to forest carbon, forests fulfil the role of net sinks, and there is carbon capture and storage in forests and harvested wood products (HWPs). Conversely, the regression analysis findings indicated that independent variable D (CZK million) and control variable TIME contribute to increasing GHG emissions to the atmosphere. According to forest carbon, forests fulfil the role of net sources.

DISCUSSION

RQ1: Can we observe an increasing trend of financial flows to forestry in the Czech Republic?

Firstly, in the period 2000–2021, there was an increasing trend of national financial flows to forestry in the regions of the Czech Republic. Due to the bark beetle calamity, financial support has sharply risen since 2017 and recorded an all-time maximum in 2021. In detail, two tendencies are visible, namely a downtrend for *Title A*, *Title C*, and *Title H* and an uptrend for *Title B*, *Title D*, and *Title I*. According to the structure changes, *Title B* represented the highest share (61–81%) each year.

As the literature review revealed, several studies work with national financial sources for forestry in the Czech Republic, for instance, Šišák (2002, 2007, 2013), Kotecký (2015), Lojda and Ventrubová (2015), and Perunová and Zimmermannová (2023).

However, studies displaying the economic aspects of bark beetle calamity in the Czech Republic are still missing.

Based on Šišák (2002, 2007), various mechanisms are available in forestry, especially ethical, normative, economic, and institutional, aiming for reasonable exploitation of forest resources in the Czech Republic. According to findings (Perunová, Zimmermannová 2023), financial contributions for forest management granted from the budget of the Ministry of Agriculture are drivers for the rise in the utilisation of bioeconomy renewable resources, such as wood biomass. Consequently, national funding sources can boost biodiversity conservation and sustainable forest management (Liagre et al. 2017). In addition, the study by Sevinç (2022) analysed financial support in line with the behaviour of forest owners. Leoussis and Brzezicka (2017) stressed the indispensability of financial support for landowners and forest owners. According to Ohmura and Creutzburg (2021), the effectiveness of economic instruments will vary depending on the financial beneficiaries involved. Moreover, soft policy interventions, such as voluntary commitments, become slightly attractive, but depending on the type of forest ownership (Danley 2019).

On the other hand, the study by Aoyagi and Managi (2004) concluded that government subsidies adversely altered the economic outlook of forestry. In the Czech Republic, a proportionately high number of national financial titles and other resources are limited in total financial amount combined with difficult organisation and administration (Šišák 2013). Forestry makes a considerable impact on rural development and the Rural Development Programme seems to be a more effective tool than national financial funding (Lojda, Ventrubová 2015). Based on Kotecký (2015), subsidies for afforestation in the Czech Republic are not optimal and seem to be targeted to areas with existing high forest cover. In certain regions, approaches are put in place to safeguard biodiversity, water, and climate regulation and recreation, although the social-environmental dimension remains far from balanced with the economic one (Sotirov, Arts 2018; Mattioli et al. 2024).

RQ2: Can we observe regional differences in financial flows to forestry in the Czech Republic?

Secondly, it can be concluded that national financial flows to forestry were not equally split among regions and regional divergences were investigated.

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First, the indicator of the financial contributions for forestry granted from the budget of the Ministry of Agriculture (*Title A – Title I*) per ha was applied (Figure 3). From 2000 to 2021, the average of the indicator was up by 447% while the indicator reached a historical level of CZK 1 528/EUR 62 per ha in the Vysočina Region (VYR) in 2021. Second, the indicator of the financial contribution to mitigate the impact of the bark beetle calamity (*Title L*) per ha was examined (Figure 5). In a summary of 2019–2021, the accumulated flows of *Title L* per ha in maximum were observed in the Vysočina Region (VYR), the Olomouc Region (OLR), and the Zlín Region (ZLR). Indeed, the peak of both indicators, such as the sum of *Title A – Title I* per ha and *Title L* per ha, was granted in 2020 to the Vysočina Region (VYR), comprising 85% of *Title L*, 10% of *Title B*, and 4% of *Title D*.

Based on the literature review, it can be concluded that studies investigating regional aspects of the national financial sources and/or studies dealing with the economic aspects of bark beetle calamity emphasising regional differences in the Czech Republic are still absent. For example, Brázdil et al. (2022), Šafařík et al. (2022), Michalec et al. (2020) and Toth et al. (2020) examined bark beetle calamity in the Czech Republic, with no regard to regional disparities in financial support.

Previous forest management can be a precondition for existing conditions in forests, and consequently influence pest outbreaks (De Groot et al. 2019). As a consequence of ongoing climate change, shifts in the disturbance regime caused by novel agents or overlapping of the historical range of variety occur (Turner, Seidl 2023). Forest reorganisation emerges as a phase determining the long-term shape of forest ecosystems, which can either persist or face regime shifts (Seidl, Turner 2022). Falcone et al. (2020) suggest essential drivers to ensure a booming forest-based bioeconomy, including the circular principle. According to Hlásny et al. (2021), an effective strategy to address bark beetle calamity is to reshape regional forest management.

RQ3: Do financial flows have a positive environmental impact on the forest bioeconomy in the Czech Republic? Concerning this research question, the forest bioeconomy in our research is represented by the indicator 'forest carbon'. The regression analysis outputs reveal that financial contributions for reforestation, establish-

ment, and tending of forest stands contribute to increasing GHG removals from the atmosphere. This implies beneficial environmental impact, as forests fulfil the role of net sinks, and carbon capture and storage in forests and harvested wood products (HWPs) is observed.

Conversely, the regression analysis findings indicated that financial contributions for green and environmentally friendly technologies contribute to increasing GHG emissions to the atmosphere. This implies adverse environmental impact, as forests fulfil the role of net sources, and carbon capture and storage in forests and harvested wood products (HWPs) are not observed.

Referring to the variable 'forest carbon', we expected that all selected national financial sources lead to increasing GHG removals from the atmosphere, as a net sink, as in studies by Jinggang and Peichen (2017), Lee et al. (2018), Pukkala (2020), Bowditch et al. (2022), and He and Ren (2023).

According to the findings, till 2017 Czech forests acted as net carbon sinks, while in recent years had become a net source. Adversity is the effect of drought, especially on tree species planted outside their ecological optimum, and the subsequent attack of insect pests. Due to biotic disturbance, removals gradually rose from 2017, maximising in 2020 (34 million m³), and falling to around 23 million m³ in 2021 (CZSO 2023). These influence reforestation, which has led to the expansion of planting broadleaved tree species, intending to avoid monocultures over a large area at the same age. Currently, afforestation and reforestation activities are more intensive, with 40 thousand ha in 2022 compared to 28.7 thousand ha in 2018 (CZSO 2023). Long-term, coniferous tree species were predominant, whereas in the period 2019–2021, the trend has changed. Considering the damaging impacts of the bark beetle calamity, the priority is on building more resilient forests, adapting to and mitigating climate change, and sustainably managing natural resources (Hlásny et al. 2017; Cramer et al. 2018; Thrippleton et al. 2023).

Financial support is a precondition to developing a support system for forestry carbon sinks (Bowditch et al. 2022). Subsidies can strengthen forest carbon capture and storage capacity and enhance the welfare of actors in forestry (He, Ren 2023). A payment of EUR 150 per tonne of carbon sequestered in forests would bring a halt to cutting (Pukkala 2020). A study by Jinggang and

Peichen (2017) focused on encouraging carbon capture and storage in forests through subsidy. The advancement of co-benefits, such as corporate social responsibility, social cohesion of regional communities, and positive environmental effects, remains the key to enhancing the competitiveness of forest carbon credits (Lee et al. 2018). Moreover, Kilgore et al. (2007) noted that financial stimulus appears to have the power to shape the decision-making of forest owners related to sustainable forest management and forest land utilisation. The results (España 2022) show that government subsidies constitute effective tools and appear to have aided the rise of forest areas. In the case of national financing mechanisms in small-scale forestry (Boscolo et al. 2010), innovation, knowledge sharing, and information exchange are crucial drivers for sustainable forest management.

The forest-based sector has several potentials in mitigating climate change. Firstly, notable forest carbon stocks/pools include forest soils and living wood biomass. Regarding living biomass carbon per ha (Forest Europe 2020), Central-West and Central-East Europe are the leaders. Secondly, in the long term, HWPs increase the carbon stock, while reducing forest sinks in the short and medium term (Pilli et al. 2015). Regarding forest land and HPWs, increasing afforestation and reforestation, reducing deforestation, and sustainable forest management are required. Thirdly, wood materials can reduce emissions by replacing emission-intensive ones while increasing removals by storing carbon in HWPs (European Commission 2021a). The positive effects of material replacement then depend on the substitution factor. The material use of wood brings opportunities for a circular bioeconomy and cascading use of biomass, where closed loops of materials are created, the added value of inputs is maximised, and the lifetime of outputs is extended (Keegan et al. 2013). Innovations, bio-based technologies, and bio-based materials are generators for the development of forest-based value chains and new business models (Giuntoli et al. 2023). The synergy of wood biomass usage in downstream industries such as textiles, chemicals, and pharmaceuticals is evident and boosts the bioeconomy. Finally, wood biomass in place of fossil fuels can achieve huge emissions cuts. In the Czech Republic, the energy mix is transforming, with a 2030 target of 28–30% renewable sources, including wood biomass (European Commission 2018a).

Regional forest carbon reservoirs offer benefits in a low-carbon economy, and a potential to contribute to climate goals. The target of the LULUCF sector represents –310 MtCO₂eq. by 2030 (European Parliament 2023a), while the national goal of the Czech Republic is 1 228 ktCO₂eq. (European Commission 2022). Moreover, Carbon Removal Certification (European Parliament 2023b) is an opportunity for the forest-based sector. Carbon capture and storage in restoring forests and in long-living wood materials and products constitute natural solutions for GHG removals under the certification framework (European Parliament 2023c).

CONCLUSION

The main purpose of the study was to examine the effects of financial support on the development of the forest bioeconomy in the Czech Republic in the period 2000–2021. Research objectives were met by applying literature review, time series analysis, spatial data analysis, cartogram and cartodiagram methods, correlation analysis, and regression analysis. Firstly, regional divergences in national financial flows were observed. Owing to the bark beetle calamity, the peak of the national financial support was detected in the Vysočina Region (CZK 4 658/EUR 190 per ha), and the Olomouc Region (CZK 2 780/EUR 113 per ha) in 2020. An upward trend – more than 6-fold growth of financial flows to forestry – was found. Secondly, the forest carbon model was discovered and tested. Financial contribution for reforestation, establishment, and tending of forest stands increases net carbon sinks while financial contribution for green and environmentally friendly technologies increases net carbon sources.

Some limitations occurred, such as a varying number of financial contributions and the availability of the data and time series. Another limitation was the originality of the data, as datasets are not commonly available and are accessible upon request.

Concerning the recommendations, policymakers should reflect on the key objective of financial contributions, i.e. emphasise the role of net carbon sinks or others. We would recommend that a regular evaluation of the provided economic and financial support be carried out, including a regional scale, as it is obvious that the situation can differ. The forest bioeconomy links to a climate-neutral

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economy for which effective economic and financial promotion is essential to sustainable development.

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