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Economic Modelling of Forest Service Providers in Hungary

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ABSTRACT

This study presents a financial modelling analysis of licenced forestry specialist services and forestry operation services based on skidding and forwarding. An enterprise needs to provide forestry specialist services on 1,500–2,500 ha and achieve 36,000–37,000 EUR turnover to finance the full-time employment of one person and to attain 10% profit on turnover. Forestry contractors that harvest wood by skidding with a farm tractor need to harvest 4,300–5,500 m^3 annually and generate 120,000–130,000 EUR income per year, while an output of 7,700–10,100 m^3 of harvested wood and 210,000–220,000 EUR of income is needed in forwarding.

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Kulcsszavak:

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KIVONAT

Magyarországi erdészeti szolgáltató vállalkozások gazdasági modellezése. Ez a tanulmány a jogosult erdészeti szakszemélyzeti és az erdészeti kivitelezési szolgáltatások pénzügyi modellezésének elemzését mutatja be. Megállapítást nyert, hogy egy vállalkozásnak 1500-2500 hektáron kell jogosult erdészeti szakszemélyzeti szolgáltatást nyújtania, és 36 000-37000 EUR árbevételt kell elérnie ahhoz, hogy finanszírozni tudja egy fő teljes munkaidős foglalkoztatását, és 10%-os árbevétel arányos nyereséget érjen el. A mezőgazdasági traktorral végzett közelítésre épülő fakitermelési szolgáltatások esetén évente 4300-5500 m^3 fát kell kitermelniük, és évi 120-130 ezer EUR bevételt kell termelniük, míg a forwarderes fakitermelés esetében 7 700-10 100 m^3 kitermelt fára és 210-220 ezer EUR bevételre van szükség.

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1 INTRODUCTION

The beginnings of today's private forestry in Hungary can be traced back to the political and economic changes that started in 1989 (Gerely – Schiberna, 2004). Like other countries in East Europe, private forests in Hungary were created by privatising former agricultural cooperative forests and partially privatising state-owned forests (Weiss et al., 2019). Significant afforestation on privately owned farmlands has also occurred since this period.

The two major prerequisites of lawful forest management are a) a Manager of Forest (MOF) with proper land use rights registered with the Forest Authority and b) a Licenced Forest Specialist (LFS) employed or contracted by the MOF. MOF can be an organisation or an individual bearing the legal responsibility for forest management. Forest policy measures (regulations and subsidies) have prioritised collective management due to the lack of forestry tradition, knowledge and capital among the new owners.

The unique characteristic of land privatisation in Hungary is that a significant proportion of private forests (65%) are in common ownership, where the owners must agree on how their forests will be managed (Mertl – Schiberna, 2017).

New owners were unmotivated to form larger management units, and many owned small properties. Thus, they were uninterested in participating in the lengthy administrative process of appointing their own MOF and LFS.

Private forest management in Hungary faced significant problems by the early 2000s. In 2000, only 413,000 ha of the 757,000 ha of privately owned forest had a forest manager registered by the forestry authority. Legal forest management is impossible without a registered forest manager.

Another indicator of the state of the private forestry sector is the area of delayed reforestation. According to regulations, reforestation must start within two years of the final cut and must be finished by a species-specific deadline. The area of delayed reforestation was 9,096 ha in 2000, of which 5,831 ha missed the start deadline, while 3,265 ha missed the end deadline. The total reforestation started in the same year was 8,795 ha.

A subsidy scheme launched in 2000 to facilitate private forestry sector development aimed to establish a network of forestry service providers. Financial support was available for enterprises that were MOFs on 200 to 4,000 ha of forest and provided LFS services to other MOFs on at least 200 ha and forestry operation services on at least 50 ha. These service hubs were called 'forestry integrators', and they were expected to extend their services to trading timber and propagation materials and to become major facilitators in rural development programs by writing subsidy applications for their partners (Schiberna et al., 2011).

Hungary accessed rural development funds when it joined the European Union (EU) in 2004. At the time, the EU's Rural Development Programme included support for advisory services, but the integrator model did not fit into this framework, so the national budget needed to maintain this service network, which was eventually discontinued in 2010.

Subsequently, the improvement in the above indicators for the private forestry sector stopped and began to decline after a few years of stagnation. In 2010, the size of delayed reforestation was 4,411 ha, while the area without a forest manager was 175,279 ha. This trend was reinforced by a legislation change that led to the cancellation of registered forest managers over a large area. Since then, private forest land without forest managers (304,589 ha in 2021) and the area of delayed reforestation (11,082 ha in 2021) have fallen back to levels seen in the early 2000s. Meanwhile, the timber markets, including firewood, which accounts for 59% of the Hungarian timber harvest, grew steadily between 2004 and 2020.

Market conditions, regulations, rural development schemes, and other subsidies strongly influence private forestry development in Hungary. Consequently, forest owners and MOFs need credible and up-to-date information to deal with the frequent variations and changes in the above factors.

Since the privatisation began, the overall change in forest area has resulted in 55.9% of the total forest area in public ownership, 1.0% in community ownership and 43.2% in private ownership (Ministry of Agriculture, 2023a).

2 PROBLEM IDENTIFICATION

According to the Forest Act (2009. XXXVII), the forest owner— or owners in the case of joint ownership—decides on forest property use, including MOF and the LFS designation. The MOF can be an owner or a third party. The Forestry Authority registers MOF in all cases. Depending on the land use contract, the owner(s) may withhold some of the use rights, such as timber removal decisions, forest reforestation type or other business decisions. However, all legal liability rests with the MOF.

The MOF must cooperate with an LFS to meet professional standards in forest management activities. Individuals or enterprises employing a forester can provide LFS services. The Forestry Authority issues a licence to foresters who have obtained the required work experience and passed the compulsory forest administration exam. LFS is responsible for the validity of forestry documentation and forestry field activity supervision.

Forestry operation contractors (FOC) perform most of the work in private forests in Hungary. Most contractors are small and have low-value machinery. Some work in other sectors outside the logging season.

Based on the above, at least four functions must be in place for forest management to start—the owner(s), the MOF, the LFS, and the contractor. A single person may perform these functions; however, in practice, they are likely performed by separate persons or companies. A capable actor is needed to coordinate the process. *Table 1* summarises why the LFS has the best potential for organisational capacity in most cases.

Table 1. Characteristics of the forest owner, the forestry manager (MOF), the licensed forest specialist (LFS) and the contractor (FOC)

<table>
<tr><th>Stakeholder</th><th>Legal knowledge</th><th>Forestry knowledge</th><th>Resources</th><th>Motivation</th></tr>
<tr><td>Owner(s)</td><td rowspan="2">No formal training, frequent changes in legislation are difficult to follow</td><td rowspan="2">No forestry tradition and education</td><td rowspan="2">Restricted</td><td>Low, especially small property size, middle-aged or young forest, or in the absence of urgent forestry intervention</td></tr>
<tr><td>MOF</td><td>Low, income from forests as an independent source of livelihood is rare</td></tr>
<tr><td>LFS</td><td>Continuous experience</td><td>Must have formal forestry education and work experience</td><td>Depends on size</td><td>High, they rely at least partly on incomes from LFS services</td></tr>
<tr><td>FOC</td><td>No formal training, mostly rely on LFS guidance</td><td>Practical skills, limited administrative skills</td><td>Lack of financial sources due to low profitability</td><td>High, FOC services are their main income source</td></tr>
</table>

A challenging step in organising forest management is knowing the legal options and frequent legislation changes in land use issues, administrative procedures, and forestry law. Understanding forest management processes thoroughly and realistically assessing the economic potential of forest management is crucial. Organising forest management requires considerable time to obtain data, maintain formal correspondence with stakeholders and complete administration tasks. Such work is time-consuming, and costs must be covered in advance.

In light of the above, forestry LFS plays a key role in developing private forestry. This article examines the minimum conditions for LFS service provider operation, including costs and minimum revenues, and calculates the minimum service area. Similarly, two types of forest operation contractors are also analysed to reveal their cost structures and minimum service volumes (area and volume of timber harvested).

3 DATA AND METHODS

This study developed models to gauge the conditions under which an LFS service enterprise can operate, estimate the costs of fulfilling these conditions, calculate the revenues needed to cover the costs and the operational area that can provide these revenues. The modelling assumes that such an enterprise operates under strict cost restrictions and aims to exceed the breakeven point.

The same modelling procedure is used to examine the financial conditions of logging services in two scenarios: one assuming a lower technical standard and one assuming a higher technical standard.

LFS and FOC services were modelled based on personal interviews with four LFS and four FOC enterprises. The interviewees were selected from various parts of the country, the operating area of which—especially in the case of larger logging enterprises—covers multiple geographical regions with various natural conditions. Although forest types, topography, soil conditions, logging techniques and other factors can significantly impact work efficiency and financial conditions, the modelling was designed to represent the average situation these enterprises face.

The contractor fees for forestry activities were obtained from the 2023 annual forestry fee survey (Ministry of Agriculture, 2023b) and adjusted according to the fees reported by the interviewees. Detailed cost structures were developed to calculate logging costs. Enterprise operating costs, including equipment rental fees, maintenance costs, salaries and overhead costs, were compiled according to the interviews.

The model calculation includes variable costs, fixed costs, target profit margin and unit service prices. The volume of services required for a profitable long-term operation—the ultimate aim of the analysis—is calculated using formula (1), constructed by the authors.

$$Q = \frac{FC}{(1-r)P-VC} \qquad (1)$$

Where:

Q:	service volume (ha; m^3)
FC:	fixed costs (EUR)
r:	profit margin on turnover (%)
P:	unit price of service (EUR/ha; EUR/m^3)
VC:	variable costs (EUR/ha; EUR/m^3)

Financial values are presented at a 400 HUF/1 EUR currency exchange rate. Original calculations were conducted in HUF; therefore, minor rounding errors may occur, but none affect the conclusions.

4 RESULTS

4.1 Model of a LFS service provider

Enterprises solely providing LFS services must keep costs as low as possible, especially at the initial development stage. Business, family infrastructure, and overhead costs (telecommunications, car) that may be combined or mixed in the short term are tolerable for such enterprises.

LFS service is the only activity of a model enterprise during its first few years of operation. Such service includes forestry operations supervision, fieldwork (designating logging area and marking trees to be felled) and administration. In addition, the LFS advises the MOF and acts on behalf of the MOF in official processes such as forest management planning and forest authority field inspections. LFS also monitors the forest area and manages and documents calamities, e.g. by submitting forest protection reports.

LFS service does not include harvested wood stock inventorying, timber sales, invoicing, etc. Writing subsidy scheme applications is not part of the basic LFS service either.

Table 2. Financial model for LFS service enterprise

Type of cost	Justification	Expenses (EUR)
Equipment rent	1 Off-road vehicle	6,000
Maintenance	Annual maintenance costs of an off-road vehicle	600
Personnel	12 monthly salary + benefits	21,425
	Working clothes	188
Overheads	Accounting and other administration	600
	Insurance	250
	Office equipment + communication + utility	750
	Marketing	750
Total fixed costs		**30,562 EUR/yr**
Operating costs	Gasoline	1.3
Total variable costs		**1.3 EUR/ha**
Profit margin	10% profit on turnover	10%
Service unit price		15-25 EUR/ha
Minimum operating area		**1,500–2,500 ha**
Revenue of the minimum service volume		**36,000–37,000 EUR**

4.1.1 Equipment and maintenance

Table 2 shows LFS service enterprise modelling. In the present model, the enterprise rents a durable off-road vehicle for 6,000 EUR to cover a fragmented and scattered service area. Equipment, such as phones, laptops, printers, software, GPS devices, etc., are partly included in overhead costs, but the model also assumes that family equipment can be used.

The off-road vehicle requires annual maintenance, including tyres, oil changes, other maintenance, and safety inspections, which total about 600 EUR. These costs are independent of vehicle usage. Hence, they are fixed costs. Gasoline is included in the variable costs.

4.1.2 Personnel

According to the Hungarian Central Statistical Office (KSH), the average gross monthly salary for full-time employees in Hungary in January–February 2024 was 1,513 EUR, subject to an 18% social security fee. The model assumes that the LFS is the only employee in this enterprise and that the LFS earns the average salary, bringing the total annual salary cost for this enterprise to 21,425 EUR.

4.1.3 Overheads

The present model does not include separate office rental costs because it assumes the free use of own property. An external company provides the accounting service for 50 EUR/month, or 600 EUR annually. The model estimates the necessary insurance to be 250 EUR per year and office equipment, communication and overhead costs to be 750 EUR per year. The marketing budget for advertising and participation in professional gatherings is 750 EUR per year.

4.1.4 Operation

Most business expenses in an LFS service enterprise are fixed; the volume of operation and the service area have little influence on costs. The only identified variable cost is gasoline for the off-road vehicle, which strongly correlates with the service area size and location(s). The present model calculates an average gasoline cost of 1.3 EUR/ha/yr.

4.1.5 Calculation of minimum service volume

The fixed cost is 30,562 EUR per year, while variable costs are 1.3 EUR/ha. The unit price of LFS service ranges between 15 and 25 EUR/ha/yr. The minimum service volume calculated with formula (1) and rounded up to the nearest 100 is 1,500 to 2,500 ha. This service area generates 36,000–37,000 EUR (rounded up to the nearest 1000) of turnover per year, which covers business expenses and allows for a 10% profit.

4.2 Logging services – low technical standards

A typical form of service logging among logging contractors is an agricultural tractor under 75kW equipped with a winch and operated by a small crew. Black locust (*Robinia pseudoacacia)* and poplar *(Populus sp.)* plantations are harvested by clearcutting followed by an artificial regeneration by planting seedlings or root-coppicing. Since there are no remnant trees or seedlings that could be damaged during harvest operations, logs are transported to the depot by skidding.

The process in such logging systems starts with motor-manual felling and delimbing. Skidding is done by a farm tractor with a winch, which takes the trunk to the depo area, where it is cut into smaller wood products. Depending on the stand properties, the logging team consists of one feller, one tractor driver, one cutter at the depot and two hand-stackers.

This equipment is unsuitable for felling stands of large trees (over 1 m^3/tree) and in areas where skidding would damage forest regeneration. This logging system is more suitable for producing small wood products (e.g. firewood), primarily because handling and stocking larger logs in the depo area would require a separate machine.

The financial modelling of the above logging service assumes a medium stand of black locust tree species with a yield of 200–250 net m^3/ha and a slope below 10 degrees (*Table 3*).

4.2.1 Equipment and accessories

The most important machine of this model enterprise is the farm tractor equipped with a roll-over frame and a forestry winch, which is rented in this case. The price of a used farm tractor is 7,500 EUR, and the forestry winch is 1,500 EUR. Both have a remaining service life of three years. The annual rental fee for this equipment is 3,000 EUR.

The team needs an off-road vehicle to commute to and from the forest. The annual rental fee of this vehicle is estimated at 1,250 EUR.

The model business is based on two chainsaws, assumed to be in operation for three years. Their rental is about 750 EUR per year.

Some smaller accessories are also needed: signs to mark the working zone for forest visitors, bins to collect waste, fire extinguishers and hand tools. The annual cost of these is estimated at 750 EUR.

The cost of workwear and safety equipment for fellers working with chainsaws is 750 EUR/worker, with a three-year expiry date. This cost includes a safety helmet, gloves, ear protection, protective trousers, jacket, safety boots, and underwear. Trousers and jackets are cheaper for hand-stackers and tractor drivers and cost roughly 250 EUR/worker with a three-year replacement period. In total, the annual cost of the team's workwear and personal safety equipment is 750 EUR.

Table 3. Financial model for logging services – low technical standards

Type of cost	Justification	Expenses (EUR)
Equipment rent	1 Farm tractor with roll-over frame and winch	3,000
	1 Off-road vehicle for 5 workers	1,250
	2 Chainsaws	750
Maintenance	Tractor maintenance	500
	Maintenance and safety inspection of chainsaws	750
	Maintenance of off-road vehicle	500
Accessories	Safety signs, rubbish bin, fire extinguisher, tools	500
	Safety equipment for the team	750
Personnel	Salary + benefits for the team (12 months)	74,750
Overheads	Accounting and other administration	600
	Insurance	500
	Communication + utility + other	750
Total fixed costs		**84,600 EUR/year**
Operating costs	Chainsaw gas and lubricant	1.12
	Chainsaw wearing parts (chain, bar)	1.88
	Tractor fuel and lubricants	1.20
	Transport of equipment	0.30
Commuting	Fuel	0.38
Total variable costs		**4.88 EUR/m^3**
Profit margin	10% profit on turnover	10%
Service unit price		22.5–27.5 EUR/m^3
Minimum service volume		**4,300–5,500 m^3/year**
Minimum operating area		17–22 ha
Required daily output*		21–28 m^3/day
Required daily output per 1 person*		4.4–5.6 m^3/worker/day
Minimum service volume revenue		**120,000–130,000 EUR**

*Refers to productive days (productive working days/total working days = 85%)

4.2.2 Personnel

The logging industry usually does not employ full-time, permanent workers and usually pays hourly wages; however, this model assumes full-time status for 12 months a year with 20 days of paid leave because finding and keeping skilled workers has become an increasing challenge, one we believe can be alleviated by offering predictable and stable incomes.

The average gross salary of the logging workers in the above-described employment scenario is 1,050 EUR per month, subject to an 18.5% social security fee. This represents a total annual salary of 74,750 EUR for a five-person team.

4.2.3 Overheads

The present model assumes the outsourcing of the most important administrative tasks of the enterprise, such as bookkeeping, tax declaration and statistical reporting and sets these costs at 600 EUR a year. Accident insurance for the machinery and the employees and liability insurance for the enterprise amounts to 500 EUR per year.

Although the enterprise does not have a separate office, it still requires office supplies, which, together with postal charges, communication fees, and other administrative overheads, equals 750 EUR per year.

4.2.4 Operation

The most significant items among variable costs of logging services are fuel and lubricants for the tractor and the chainsaws and the saw chain and saw bar replacement. These items depend heavily on whether hardwood or softwood is harvested. Here, we assume hardwood production.

When logging in a new area commences, the farm tractor is transported or driven to the new location, depending on the distance. The logging team needs to commute to and from the forest, the distance of which can vary. *Table 4* presents these cost items.

Table 4. Major variable costs of logging services – low technical standards

Cost item	Rate of use	Unit cost	Logging costs
Saw chain	1 chain/50 m^3	62.5 EUR/chain	1.25 EUR/m^3
Chainsaw bar	1 bar /100 m^3	62.5 EUR/bar	0.625 EUR/m^3
Chainsaw lubricant	0.2 l/ m^3	2.5 EUR/l	0.5 EUR/m^3
Chainsaw fuel	0.5 l/m^3	1.25 EUR/l	0.625 EUR/m^3
Tractor fuel	1.0 l/ m^3	1.25 EUR/l	1.25 EUR/m^3
Tractor relocation	1 time per 1000 m^3	250 EUR/1000 m^3	0.25 EUR/m^3
Workers daily commuting	10 l/day -> 0.3 l/m^3	1.25 EUR/l	0.375 EUR/ m^3

4.2.5 Calculation of minimum service volume

The price of logging services varies over a broad spectrum. According to forestry market statistics, the service fee for black locust final harvest on less than 10-degree slopes in 2023 was 24.7 EUR/m^3 (KSH, 2024). The model calculates 22.5 and 27.5 EUR/m^3. The minimum service volume, calculated according to formula (1) and rounded up to the nearest 100, was 4,300–5,500 m^3/year, which (based on an average net timber yield of 250 m^3/ha), implies 17–22 ha of logging work a year.

On average, there are 250 working days and 20 paid holidays a year. Furthermore, about 15% of working days are unsuitable for logging due to weather factors. Thus, minimum service volume can only be attained if the team achieves an average output of 21–28 m^3/day on actual working days, which means an output of 4.4–5.6 m^3/person/day.

The turnover for the minimum level of service is 120,000–130,000 EUR, rounded up to the nearest 10,000.

4.3 Logging services - high technical standards

Another conventional logging method is the motor-manual felling combined with forwarding, which causes less soil disturbance and less forest regeneration damage. Forwarders can carry 10–15 m^3 of timber to distances up to 1 km. In comparison, the efficient skidding distance for a farm tractor is 100–200 m.

In this logging method, the tree is felled, delimbed and then cut into half by one feller. The forwarder takes the pre-cut wood to the depot area, where three workers cut them to size. The forwarder also loads the wood into stacks or piles, according to product type. This logging method can be operated with a crew of five.

As before, the modelling assumes a medium-yielding black locust (*Robinia pseudoacacia)* stand with a net yield of 200–250 m^3/ha and a slope of less than 10 degrees. (*Table 5)*

The two logging methods are similar in workflows and costs; therefore, the description below covers only the differences.

Table 5. Financial model for logging services - high technical standards

Type of cost	Justification	Expenses (EUR)
Equipment rent	1 Forwarder	37,500
	1 Off-road vehicle for 5 workers	1,250
	4 Chainsaws	1,500
Maintenance	Forwarder maintenance	7,500
	Maintenance and safety inspect. of chainsaws	1,500
	Maintenance of off-road vehicle	500
Accessories	Safety signs, rubbish bin, fire exting., tools	500
	Safety equipment for the team	1,075
Personnel	Salary + benefits for the team (12 months)	85,963
Overheads	Accounting and other administration	600
	Insurance	2,500
	Communication + utility + other	750
Total fixed costs		**140,138 EUR/yr**
Operation	Chainsaw gas and lubricant	1.12
	Chainsaw wearing parts (chain, bar)	1.88
	Forwarder fuel and lubricant	2.5
	Transport of equipment	0.38
Commuting	Fuel	0.37
Total variable costs		**6.25 EUR/m^3**
Profit margin	10% profit on turnover	10%
Service unit price		22.5-27.5 EUR/m^3
Minimum service volume		7,700–10,100 m^3 /year
Minimum operating area		31–40 ha
Required daily output*		39-52 m^3/day
Required daily output per person*		7.8–10.3 m^3/worker/day
Minimum service volume revenue		**210-230 000 EUR**

*Refers to productive days (productive working days/total working days = 85%)

4.3.1 Equipment and accessories

We assume the logging enterprise rents a new forwarder for 37,500 EUR annually. In financial terms, this is the same as buying a new forwarder for 375,000 EUR and selling it for 187,500 EUR in 5 years.

According to the working method, the model requires four chainsaws, which can be rented for 1,500 EUR per year.

Since the team composition is different from the previous logging method, safety equipment and workwear costs are re-calculated for four chainsaw workers and a forwarder driver. Considering a three-year replacement period, the total cost is 1,075 EUR.

4.3.2 Personnel

Logging with a forwarder requires more chainsaws and, in the case of the forwarder operator, higher qualifications. Although the crew size is the same as the farm tractor logging, the labour cost is 15% higher. In total, this model enterprise spends 85,963 EUR a year on the crew's salary.

4.3.3 Overheads

The only difference in the operating costs of the enterprise compared to the previous model is the higher insurance cost (2,500 EUR) due to the higher asset value.

4.3.4 Operation

In the present logging method, the forwarder not only carries the wood to the depot but also needs to stack and pile the wood products. In addition, forwarders typically operate at greater distances. The fuel consumption per harvested volume is more than for skidding with the farm tractor, 1.3 l/m^3.

Forwarders are usually transported to longer distances and with larger transport vehicles; therefore, the relocation cost is higher, 0.38 EUR/m^3.

4.3.5 Calculation of minimum service volume

The minimum service volume, calculated according to formula (1) and rounded up to the nearest 100, is 7,700–10,100 m^3/year, which, based on an average net timber yield of 250 m^3/ha, represents 31–40 ha of logging work annually.

Based on the above calculation, the crew is expected to achieve an average output of 39–52 m^3/day on actual workdays, which translates into an output per person of 7.8–10.3 m^3/day.

The turnover for the minimum level of service is 210,000–230,000 EUR, rounded up to the nearest 10,000.

5 DISCUSSIONS AND CONCLUSIONS

5.1 Intellectual services

There is a clear distinction between two forms of forestry services in the literature: forestry consultancy and contractor services. In many countries, forestry advisory services are a forestry policy instrument designed to support private forest management, while in other countries, they are provided by private organisations on a market basis or with budget support (Lawrence et al., 2020). A comparable situation exists in the Balkan countries, but a separate Forest Extension Service was established in Croatia to supply services such as professional training and seminars (Glück et al., 2011). Forest contractor service providers, however, are private companies that typically operate under free market conditions. Although the internal conditions of each European country—natural conditions, forest characteristics, ownership and management, economic and labour market conditions, etc.—differ, these enterprises have very similar characteristics and face similar challenges (Rummukainen et al., 2006).

Forestry-related intellectual services can be classified into many distinct categories depending on their purpose, the type of activity, and the responsibilities attached. *Table* shows one way of categorising these services; some require additional qualifications.

Table 6. Categories of forestry services and their characteristics

Categories of intellectual services	Purpose of the service	Service output
Expertise	Expert examination of individual cases	Expert opinion, typically subject to eligibility e.g. forensic experts
Advice	General advice, exploring opportunities, e.g. market and funding opportunities.	Information materials
Engineering	Long-term plans or technical plans beyond the scope of day-to-day operations	Afforestation plan Forest management plan Road construction plan
Supervision	Ensuring forestry operations' compliance with regulations	Technical administration Field preparation Field inspection
Site management	Putting forestry skills into practice	Field management of operations

Expertise, i.e. expert opinion, is a service purely based on technical knowledge. The expert should not consider stakeholder interests, regardless of how the service is financed. Such expertise is typically used to support negotiations in disputed cases or official processes, e.g. forensic expertise. Such services are usually controlled by a third party and entail licencing or accreditation to ensure high standards.

Advisory services are general advice, including face-to-face consultation or even formal training, either on an ad hoc basis or through a long-term contact. Consultant seeks to provide beneficial advice to its partner, which usually includes identifying forest-related opportunities, helping to formulate forest management objectives, etc.

Forest engineering covers tasks that require forest engineer qualifications at a minimum of a BSc level. Typical examples include elaborating a forest management plan, an afforestation plan or a road construction plan.

Depending on national legislation, foresters can be responsible for ensuring that forestry operations comply with technical standards, including those set by legal regulations. In such cases, service providers act on behalf of the forest manager and are responsible for the technical administration and field inspection of the forestry operations. Field preparation tasks of an LFS described above also fall into this category.

The major difference between site management and supervision is that site management includes business decisions, and the service provider is responsible for the successful and efficient completion of forestry operations. A site manager controls and manages the contractor, decides what to produce, administers timber sales and other business processes, etc.

Forestry intellectual services can be classified by their content, the type of service providers and their motivations (*Figure 1)*. One source of intellectual services may be the state, which may provide support services either through a specialised advisory body or through its authorities or agencies. The primary purpose is to provide general information, facilitate legal compliance and promote subsidies and other forest policy measures. The impact of public intellectual services, if not accompanied by a financial incentive, is often only indirect or has an effect in the long term (Andrejczyk et al., 2016, Butler et al., 2014).

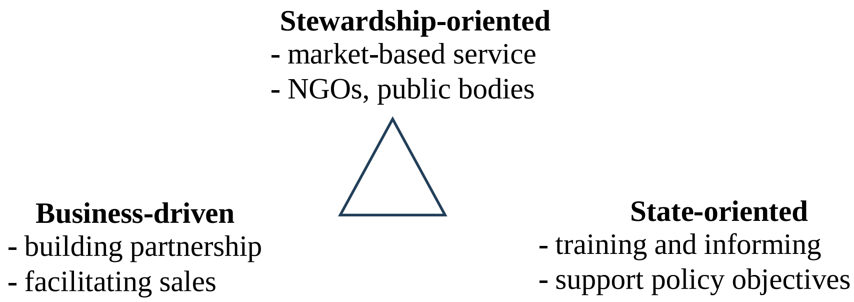

Figure 1. Characteristics of intellectual services providers by provider status

The various information campaigns and social marketing tools that encourage knowledge transfer or behaviour, regardless of how much they are targeted to forest managers (Butler et al., 2007), cannot be considered intellectual services.

The counterpoint to public intellectual services is the free or low-cost services offered by wood industry businesses willing to secure their access to raw materials. This type of service can only be viable in the long term if the interests of the service provider are also considered. Timber traders buying standing wood and managing logging are in this category (Curtis et al., 2023).

The purest form of intellectual services is when the MOF cooperates with the service provider on a market basis, and the interest of the MOF is the primary consideration. Associations, chambers and other cooperations of the MOFs can offer more affordable services. Training courses and workshops that combine knowledge transfer with planning and other practical programmes can also be included here (Zobrist et al., 2016).

Our modelling in the present study was based on a market-driven service situation aiming at long-term contractual cooperation between the MOF and the LFS. The calculations show that to run an LFS enterprise, assuming full employment of one professional, 1500–2500 ha of operational area would be needed, which would require a turnover of 36,000–37,000 EUR at 2023 prices.

In practice, LFS service enterprises provide further services and more specialised forest engineering services, such as afforestation planning, site surveying, administration of forest conversion, elaboration of management plan for continuous cover forestry, mapping, building fences against wild game, etc.

LFS service enterprises can help MOFs apply for subsidies or development grants. They are more informed about the opportunities in the first place, but they are also more capable of preparing the application documents with detailed technical information, and they have more confidence to take responsibility for meeting strict requirements.

5.2 Contractor services

The defining characteristics of forestry operation contractor services are that they are essentially performed by small enterprises operating in two different market segments. In the market of state-owned forestry companies, the bargaining power of forestry service providers is very weak. Prices are set by the customer, or at least competition among service providers can be generated. Accordingly, contractors are forced to reduce costs, which affects labour costs and the purchase, maintenance and operation of work equipment.

Consequently, such companies work with machines with low ergonomic and safety standards. Another consequence is that they cannot afford skilled labour, which, combined with poor working conditions, leads to ongoing labour problems. Due to the combined effect of the above factors, these enterprises are inefficient and, often, unprofitable. *(Figure 2)*

The advantage of this market is that state companies place large orders on the market, so the amount of work is more reliable and predictable. Although the independent development of service providers is not assured, the client can help the service provider by renting out up-to-date equipment and by developing long-term business relationships.

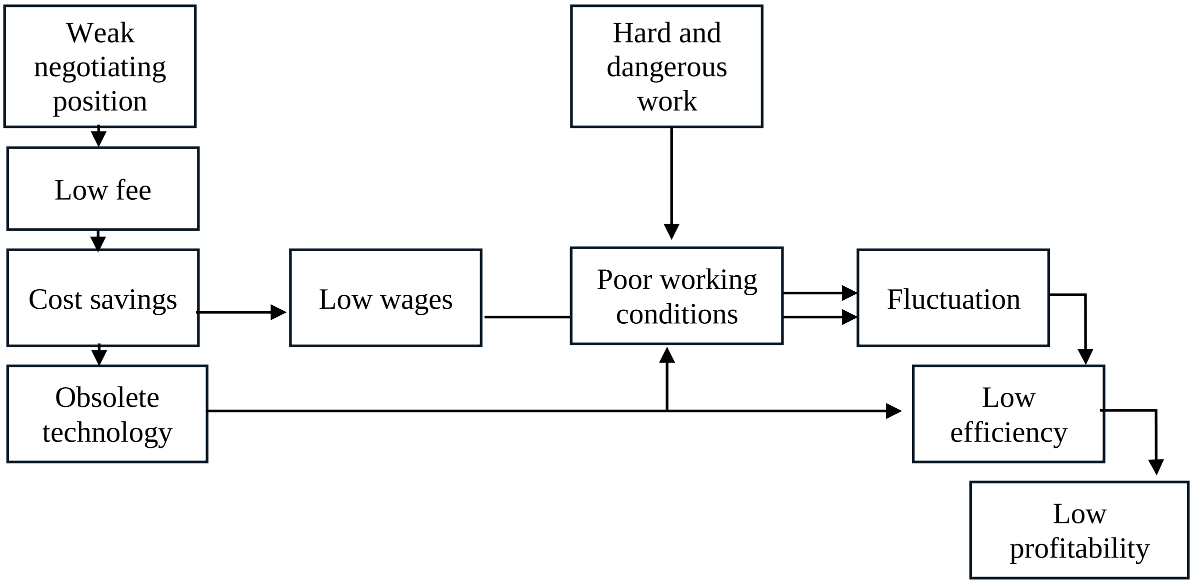

Figure 2. Consequences of low bargaining power of forestry contractors

In contrast, contractors in the private sector have stronger bargaining power, as some clients can only offer small jobs for which there is not much competition. If private forest owners and managers had the appropriate machinery and skills, they could perform the forestry work themselves, but they seldom do. This situation allows forestry contractors to negotiate a fee in line with operating costs. In such a market, the incentive to comply with contractual agreements is low due to casual business relationships, and legal enforcement is often unviable.

In the private forestry market, there may also be a reverse asymmetry between the service provider and the customer, where the service provider has more knowledge of the timber market than the client and, therefore, buys and trades timber in addition to harvesting *(Table 7)*.

Table 7. Characteristics of forestry contractors in different market segments

	Public sector	Private sector
Negotiating position	Customer dominates	Balanced between customer and service provider
Price	Low	Market-driven
Type of cooperation	Long-term, large orders, contractor rents machinery from client	Occasional and/or small orders compared to capacity
Trade opportunities	Not typical, at most for firewood in small quantities	Selling standing wood to contractor is common

In our analyses, we based the modelling of forestry service enterprises on the operations of real enterprises but used a significantly different logic to account for personnel costs than what was observed. Workers are employed primarily on a day-to-day basis in the forestry service sector, which allows for flexibility when adjusting labour to the volume and nature of the work. However, given the increasing difficulty in retaining skilled and reliable workers, it was considered appropriate to assume full-time employment.

Two variants of logging services were studied, both widely used and could be a good starting point for an intellectual services company looking to broaden its services range. In the first option, the focus was on cost savings, and a low-tech second-hand farm tractor was chosen as the main machine. In the second version, we started with a simpler logging service but assumed the purchase of a more advanced and newer forwarder.

The main difference between the two logging service solutions is that the farm tractor option only allows the production of small products that can be moved manually. For this reason, the logging crew requires loaders in addition to sawyers. Another notable difference is that the carrying capacity of a forwarder is significantly higher than that of a farm tractor, about two to three times, so at least twice as many sawyers are needed to service it.

The calculations show that fixed and variable costs are lower for logging with a farm tractor. An annual output of 4,300–5,500 m^3 is required to achieve the targeted 10% return on turnover ratio, which assumes an output of 4.4–5.6 m3/person/day.

The fixed cost of forwarder harvesting is 67% higher, and the variable cost is 28% higher than for harvesting with a farm tractor. The volume required to achieve the targeted 10% return on a turnover ratio of 7,700–10,100 m^3/year is significantly higher (76%–81%), translating into a performance of 7.8–10.3 m^3/person/day. These productivity values are significantly lower than those observed in practice, suggesting that there are larger margins to achieve profitability in forwarder logging and that higher profits can be achieved compared to the target. However, a major disadvantage of forwarder logging is the high value of machinery, which requires higher capital or a stronger credit rating than for a much lower-value farm tractor.

According to our model, forest service providers offering forestry advice are expected to generate 36,000–37,500 EUR per year to cover their income and other expenses. Those providing logging services on lower and higher technical standards should generate 120,000 – 130,000 EUR per year or 210,000–220,000 EUR per year, respectively.

The forestry services market in Hungary is conservative (slow adaptation, lack of innovation) and based on the provision of services in the field of logging and forest consultancy. In the current macroeconomic circumstances, this causes problems in the forestry sector, associated with low prices for the services provided and a lack of workers in this market.

Based on the study results, we can conclude that forest service providers depend heavily on work efficiency, as labour costs are increasing and are expected to increase further. Therefore, logging enterprises are motivated to invest in machinery. Switching to forwarding from skidding, for instance, may increase labour costs while decreasing the number of workers, but due to the considerable leap in efficiency, the labour costs per harvested wood decrease.

This trend will be reinforced by the depopulation of rural areas. In addition, mechanisation can be beneficial from an environmental (soil protection) and work safety point of view. However, small logging companies often lack capital and a solid business history, which entails a low credit rating.

Forestry consultancy is not only the main source of technical knowledge in private forestry, but it also represents the most important organising power of the sector. Without this network of forestry professionals, it would be much more difficult to achieve forest policy and rural development objectives. Their livelihoods depend on their ability to accumulate sufficient operational area, as calculated above.

Modelling limitations must be considered when interpreting these results. In particular, the models were calculated based on average conditions, entailing that the conclusions may not be uniformly applicable in all regions with various combinations of natural and economic conditions.

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A Sustainable University Model Developed and Applied by the University of Sopron

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ABSTRACT

The University of Sopron has developed the Sustainable University Model of the University of Sopron (SUM-UoS) based on its best practices and employing a systemic approach that incorporates sustainability criteria. The Institutional Sustainability Strategy defines the university's vision and SMART goals, for which it assigns an Implementation Program. Through university measures and work packages (WP), the model supports the implementation, operation, and continuous development of a Sustainable University. The SUM-UoS exists within a pyramid model aiming to create a university operating culture that prioritizes sustainability and expands it to other sectors and wider societal circles. Stemming from its Sustainability Strategy, the university has announced its "Sound of Earth University of Sopron" Implementation Program (SOE-IP), which is under trademark. The implementation program of measures aligns with the UN Sustainable Development Goals (SDGs) and provides a framework for the complex implementation and continuous development of the institutional sustainability culture. An essential element of the SOE-IP is the "University as a Living Lab Concept" approach.

TANULMÁNY INFÓ

Kulcsszavak:
Fenntarthatóság a gyakorlatban
Piramismodell
Fenntartható egyetem
Megvalósítási program
Föld Hangja

KIVONAT

A Soproni Egyetem Alkalmazott Fenntarthatósági Modellje. A Soproni Egyetem a fenntarthatósági kritériumokon nyugvó, rendszerszemléletű megközelítést alkalmazva, legjobb gyakorlatai alapján létrehozta a Soproni Egyetem Fenntartható Egyetem Modelljét (SOE–FEM). Intézményi Fenntarthatósági Stratégiájában meghatározza vízióját, SMART céljait, amelyekhez Megvalósítási Programot rendel. Egyetemi intézkedéseken, munkacsomagokon (WP) keresztül a modell támogatja a Fenntartható Egyetem megvalósítását, működtetését és folyamatos fejlesztését. A SOE–FEM egy piramismodellben ölt testet, amellyel cél egy olyan egyetemi működési kultúra kialakítása, amely a fenntarthatóságot prioritásként kezeli, és más szektorokban, szélesebb társadalmi körben is tovább terjedhet. A Fenntarthatósági Stratégiára alapozottan a Soproni Egyetem meghirdette a védjegy oltalom alatt álló „Sound of Earth University of Sopron" Megvalósítási Programját (SOE–MP). Az intézkedéseket felvonultató implementációs program összhangban van az ENSZ Fenntartható Fejlődési Célokkal (SDG), és keretet ad az intézményi fenntarthatósági kultúra komplex gyakorlatba ültetésének és folyamatos fejlesztésének. A SOE-MP lényeges eleme az „Egyetem, mint Élő Labor (Living Lab Concept)" megközelítés.

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1 INTRODUCTION

Universities aim to help implement the 17 UN Sustainability Goals, which guide sustainable development in higher education institutions (Chankseliani–McCowan, 2021). While Žalėnienė and Pereira (2021) note that universities contribute decisively to implementing seven UN Goals (1, 3, 5, 8, 12, 13, 16), many other studies have created models to understand and analyze the goals and the methods leading to them (Gutiérrez–Mijares et al., 2023).

The studies vary in their models of sustainability in higher education (Velazquez et al., 2006; Urquiza Gomez et al., 2015). While Souza Silva et al. (2022) analyze campus energy consumption and its related costs from a technical perspective, Giannetti et al. (2023) base their model on student attitudes and student rankings based on performance, happiness, and ecological footprint. Using cross-impact matrix multiplication, Menon and Suresh (2022) discovered ten factors that support sustainability in universities, including political aspirations, sustainability audit, and institutional commitment.

Many universities have set strategic objectives to ensure sustainable operations (Brundiers et al., 2021); however, various environmental, social, and economic conditions lead to distinct paths to sustainable university operations (Salvia et al., 2019). According to Dlouhá et al. (2017), universities in the Central and Eastern European region, including Hungary, have had to abandon the ideologies of the pre-1990 system and orient their institutions towards green thinking. Comprehensive strategies that impact an entire institution appear most successful. Silova (2009) found that the sustainability performance of Hungarian universities ranks among post-socialist countries. Opportunities for sustainable development and a green transition broadened significantly after Hungary joined the European Union in 2004. The University of Sopron hopes to serve as a model for other universities in Hungary and Central Europe (Fábián et al., 2023).

2 MATERIALS AND METHODS

Organizational approach: The University of Sopron is a significant intellectual, educational, and research center in western Hungary. Centuries of tradition permeate education at the university’s four faculties—Faculty of Forestry, Faculty of Wood Engineering and Creative Industries, Elek Benedek Faculty of Pedagogy, Sándor Lámfalussy Faculty of Economics—and at the Forest Research Institute, founded in 1898. The Forest Research Institute’s research and development projects support sustainable forest management (Prins et al., 2023) in a wide range of fields, including ecology, silviculture, forestry breeding, forest protection, plantation-like tree production, and economics (Prins et al., 2023). Our university strives to shape natural, social, and human environments. Its activities aim to preserve and improve the quality of life through environmentally conscious thinking (Urbański, 2020). The university cultivates moral and human values through operations and objectives to improve and enhance the region and the country.

Within the framework of its operational model change (becoming a foundation-maintained university), the University of Sopron has put sustainability at the heart of its activities, including education, research, services, third mission initiatives, and institutional operations.

Tradition-based and strategic approach: Due to its traditions and history, the University of Sopron has embraced the “Green University” concept since its inception. It strives to be a constantly renewing, determinant, and valuable academic knowledge center in Central Europe. The development of green infrastructure and social awareness is a strategic goal, and the university aims to achieve its milestones by communicating the message of net-zero climate neutrality (Köhnke, 2023; Mishra, 2023), climate and nature positivity, and environmental awareness by actively involving university students and the public.

Sustainability is a key focus of the University of Sopron's four university faculties and its research institute, and it increasingly influences its day-to-day operations. The university can engage in knowledge-intensive management and sustainable use of forest ecosystems (Hein–Van Ierland, 2006; Chen, 2022). The wood produced serves as the basis of a sustainable biomass-based economy. In addition to research in the natural sciences, climate adaptation, and engineering, the university addresses complex sustainability issues in environmental education, pedagogy, economics, and social sciences.

Educational approach: We have implemented a curricular reform at our university by integrating an elevated level of sustainability in all our courses. Sustainability pervades the whole curricula of some courses (e.g., forestry engineering, wood engineering, environmental engineering, and conservation engineering). In others, it appears in blocks (e.g., wood architecture aspects of architecture, environmental education issues in early childhood education and kindergarten, and ecological economics aspects of economics courses).

Nature-based approach: The University of Sopron pays special attention to climate and biodiversity protection and ecosystem restoration in its sustainability efforts (Doelman, 2022). It is a founding member and the first Hungarian registered member of the "Nature Positive Universities Alliance" (NPU 2022), a global network of universities launched by the United Nations Environment Program (UNEP) in partnership with the University of Oxford. The University of Sopron has registered its development programs through SMART targets (Nature Positive Pledge). The university's main objectives are the comprehensive development of the Botanical Garden (campus development), the shift towards institutional carbon neutrality, and the Loyalty Forest afforestation program.

Knowledge sharing approach: The University of Sopron is an outstanding example of sustainability implementation in Hungary. It aims to make its activities available to partner institutions as best practices and is moving towards dialogue, knowledge sharing, joint sustainability courses, and peer learning through networking. The University of Sopron is a founding member of the Sustainability Platform of Hungarian Universities (SPHU 2022), a group of Hungarian higher education institutions committed to implementing and achieving the 17 UN Sustainable Development Goals.

Through its sustainability-related activities and performance, the university contributes to both its development and that of future generations. As Hungary's "Green University," it is fully committed to initiatives that support economic, social, and environmental sustainability. This commitment is also conveyed through the university's motto, "Naturally with You!" which emphasizes the interconnectedness of individuals and nature.

The University of Sopron decision-makers, including the green university panel, have created their sustainability model. This framework defines the relevant criteria from a general and economic perspective, providing a structured approach to integrating sustainability into university operations.

3 RESULTS AND DISCUSSION

3.1 The Sustainable University Model of the University of Sopron

Societal expectations regarding sustainable development, transparency, and accountability have emerged. Mounting environmental pressures from pollution, climate change, inefficient resource use, waste management, ecosystem degradation, and biodiversity loss have affected social standards for sustainable development, transparency, and accountability, motivating organizations to adopt a systematic approach to support these efforts (Velazquez et al., 2006; Urquiza Gomez et al., 2015; Souza Silva, 2022; Menon–Suresh, 2022).

In response, the University of Sopron has developed the Sustainable University Model (SUM-UoS) based on best practices, employing a systems-based approach grounded in sustainability criteria. The Institutional Sustainability Strategy (UoS 2019) presents the university's vision and SMART goals to which it assigns an Achievement Program. The model supports the implementation, operation, and continuous improvement of the Sustainable University through University actions and work packages (WP).

The university also lays the foundations for strategic steps that extend beyond theory by putting sustainability, environmental protection, and conscious and voluntary conservation into practice. The pyramid model in *Figure 1* shows the Sustainable University Model of the University of Sopron (SUM-UoS), developed in detail based on a logical structure. Through the model, we aim to create a university culture that prioritizes sustainability. The arrows illustrate the relationships between levels. With the help of implementers and stakeholders, this university-sustainability culture can spread within higher education, other sectors, and society. Implementers can administer recommended the university's best practices and projects in their organizational context in a tailor-made way. In the following sections, we provide an overview of this.

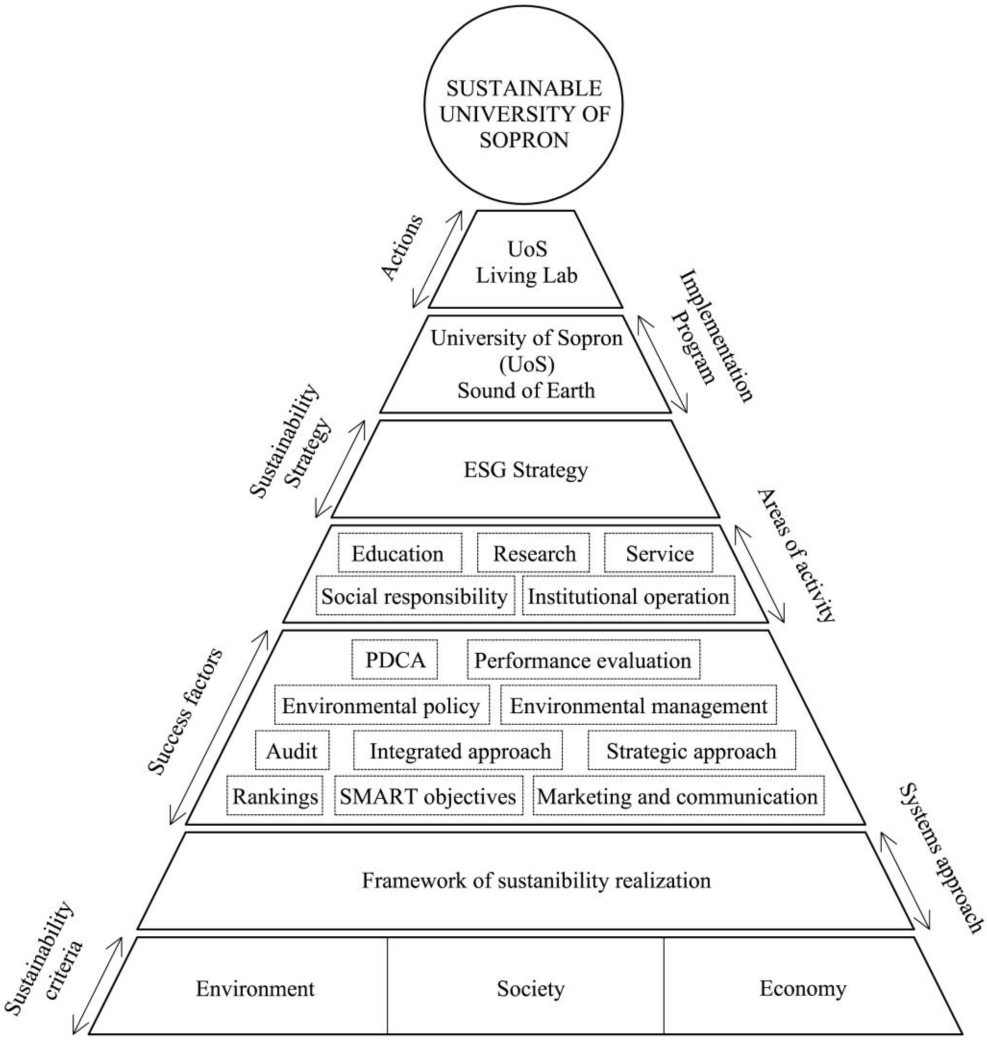

Figure 1. Pyramid model. The Sustainable University Model of the University of Sopron (SUM-UoS).

The University of Sopron Sustainable University Model is based on sustainability criteria (triple bottom line) (Jum'a et al., 2022) and a systems approach. Concerning its environmental impact, the University of Sopron systematically integrates and defines itself in its stakeholder relations and physical, landscape, and organizational environment.

The University of Sopron is certified according to the international standard ISO 14001:2015 Environmental Management System (EMS). As a framework, the model continuously improves institutional environmental performance and contributes to sustainability pillars. Based on environmental management system components, the structure defines scope, roles, responsibilities, and authorities, establishes environmental policy, monitors and addresses compliance obligations, sets SMART targets, and provides support and resources. It also ensures documentation, readiness, marketing communication, and management review.

Several success factors influence the Sustainable University Model of the University of Sopron (SUM-UoS) effectiveness, including management and staff commitment, a strategic approach, an integrated approach, applying the PDCA principle, the continuous improvement principle (ISO 2015), the process approach, developing a conscious self-evaluation system, developing evaluation cycles, third-party validation, and environmental and sustainability performance assessment.

Environmental and sustainability benchmarking can occur in many ways. Successfully certifying an institutional environmental management system to the MSZ EN ISO 14001:2015 standard demonstrates compliance with the international standard requirements. The university must be able to compare the outcomes of its efforts with those of other higher education institutions on a national and international scale. Participation in international university sustainability rankings (UI GreenMetric 2023; THE Impact Rankings 2023) provides an excellent opportunity to do just that. The rankings employ a set of predefined indicators to measure and demonstrate performance, responding to changing environmental conditions.

The model includes traditional university activities, including teaching, research, service, third missions, and institutional operations. Transparent operations and economic sustainability that adhere to environmental, social, and governance (ESG) criteria are vital (Khan, 2022; Baratta et al., 2023). A sustainable approach guides activities organized innovatively around ESG compliance and the UN Sustainable Development Goals (SDGs), with a significant thematic overlap.

The University of Sopron has launched its trademark-protected Sound of Earth University of Sopron Implementation Program based on the Sustainability Strategy (*Figure 2*).

Figure 2. Protected trademark of the Sound of Earth University of Sopron Implementation Program

The implementation program aligns with the UN Sustainable Development Goals but extends beyond mere SDG compliance by providing a framework for the complex implementation and continuous improvement of an institutional sustainability culture.

The Sound of the Earth University of Sopron Implementation Program comprises thematic work packages based on SDGs (UN 2015) (*Table 1*). The University as a Living Laboratory (Kumdokrub et al., 2023; Verbeek et al., 2023) framework includes the partnership work package, planet work package, people work package, prosperity work package, and peace work package. In action, the balance between theory and practice is paramount. The Living Laboratory Concept, which provides a framework for the work packages and action areas, is a vital element. The Living Laboratory Concept involves the multifunctional use of the green and built campus environment in the service of sustainability. Students, teachers, mentors, researchers, and employees develop their ideas in a real environment and can test their implementation through feedback loops.

Table 1. Areas for action in the Sound of Earth University of Sopron Implementation Program thematic work packages

The University as a Living Laboratory				
Partnership WP (SDG 17)	Planet WP (SDG 6, 12, 13, 14, 15)	People WP (SDG 1-5)	Prosperity WP (SDG 7-11)	Peace WP (SDG 16)
Strategy	Environment	Policies	Renewable energy	Moral
Organization	Plan documents	Training	Conditions	Individual
Dashboard	Transport	Library, databases	Finance	Performance evaluation
Network of relations	Institutional operation	Incentives	University welfare	Catalyst
Activity		Green Hygiene	Expert databases	Dissemination
		Community involvement	Procurement	
			Food/Nutrition	
			Outdoor activities	

The following outlines the individual work packages concerning integration and international best practices. The “Partnership WP” (SDG 17) work areas and related system components are also shown below. Developing a sustainability mission statement and vision element capturing the necessary philosophy and attitude is essential to the well-articulated representation of sustainability in the institutional “Strategy” and provides a framework for a university sustainability strategy reflecting an integrated approach.

An “Organization” responsible for sustainability is required to ensure efficient operation. Defining this entails documenting the institutional sustainability story, identifying the significant achieved and targeted milestones, and comprehending the foundation of sustainability identity. To meet the needs of the present and the future, it is necessary to establish a coordination-based sustainability organizational structure that is implementable at the level of a designated responsible individual or a working group. Within the organization, data managers ensure the continuous availability of inventory data required for sustainability performance indicators. Furthermore, within organizational units, additional responsible individuals acting in the role of sustainability ambassadors assist in facilitating the work.

A "Dashboard" provides transparency, quantification, knowledge, awareness, and management based on measured data by making public data on sustainability (e.g., instantaneous trends in GHG emissions) available in time series or even in real-time.

A vast "Network of Relations" is critical to successful information exchange and collaborative efforts. Global thinking could occur at the international level, while local action can occur at the university–city–region level (Vinogradova et al., 2020).

Whether general or specific, the "Activity" section of a university profile outlines the achievable sustainability efforts. Performance is developed along the specificities of the main activities of sustainability teaching, learning, research, awareness, and service. The University and Community Plan Documentation System (Master Plan) provides a systematic and methodical approach and comprehensive activity planning. As a system theory of the Living Lab Concept, the university sets the stage for concrete implementation, which can be intricately linked to various campaigns (Alsaati et al., 2020) (e.g., special days, TeSzedd!, voluntary waste collection movement).

The following characterize the "Planet WP" (SDG 6, 12, 13, 14, 15) activity areas. The institution also positions itself at the level of environmental complexes and systems to comprehend a sustainable "Environment." The development of a green environment, the enhancement of nature positivity and biodiversity at the natural environment level, the continuous improvement of infrastructure at the artificial environment level, and the system elements of landscape-level sustainability research at the environmental system level provide the opportunity for a complex approach.

Concerning the Master Plan, various "Planning Documents" outline and elaborate on the main directions, as well as the methods for ensuring compliance with specific requirements. Such documentation may include the Sustainability Report, Land Use Plan, Climate Strategy, GHG Inventory, Carbon Footprint Calculation, Carbon Neutrality, CO2 Reduction Plan, Climate Action Plan (Malthan and Hill et al., 2019), Watershed Strategy (Li et al., 2022), Waste Management Plan, and Zero Waste Action Plan (Hannon et al., 2019).

"Transport" is responsible for the direct and diffuse environmental impacts and the indirect background impacts. Optimizing areas for sustainable (public) transportation (Luttik–Maters, 2022), commuting, posting, car-free and pedestrian-friendly campuses, zero-emission vehicles, carpooling (Werkmeister et al., 2021), business air travel, and increasing efficiency should be prioritized.

In addition to traditional university activities, sustainable "Institutional Operations" mandate several tasks to achieve the lowest possible environmental impact from operations. In addition to conscious institutional waste management, separate collection (Gulyás and Veres, 2023), and composting (Saalah, 2019), emphasis should be on reusing materials, prioritizing durable products, and eliminating paper and plastic (Gherheş et al., 2021). In the fight against global warming, institutional climate protection and adaptation, conscious institutional energy management (Javed, 2021), and energy efficiency enhancement are both priorities and significant economic issues. Sustainable water management entails reviewing institutional water management, water conservation, rainwater retention (Pachamuthu, 2021), water protection, and wastewater management. Together with the green building guidelines (Abdelalim et al., 2015), good orientation, natural ventilation, natural lighting options, and air conditioning through a green environment enable a variety of advantages. The system element of sustainable consumption (Castillo Longoria et al., 2021) allows and plans careful resource management.

The "People WP" (SDGs 1-5) appear below. The institution should reconsider its human-related policies, including child protection, maternity and paternity policies, lifelong learning, and accessibility, in the "Policies" activity area.

“Training” increases awareness and competence. It should include sustainability training for staff and students and continuously monitor sustainability courses, particularly climate education. Sustainability micro-certificates certify the acquired competencies and complement the respective diplomas. The maintenance and development of “Library Services and Databases,” available to all, provide strong support.

Success requires effective “Incentives” like sustainability science programs, sustainability scholarships (students, teachers, researchers), climate scholarships (students, teachers, researchers), and support for priority research groups.

The recent pandemic and infectious diseases in general highlight the importance of hygiene and environmentally friendly cleaning products, i.e., constantly emphasized “Green Hygiene” solutions.

Student action groups, organizing sustainability events and programs, and regular news and reports all help to achieve “Community involvement.”

The energy trilemma prioritizes “Affordable, clean, renewable energy and security of supply” for the “Prosperity WP” (SDGs 7-11). An effective WP requires the right “Conditions,” i.e., proper working, education, and learning environments and, in a broader sense, the harmony of the systemic elements of urban ecology and innovation (Wu, 2014).

The “Finance” domain must address climate change and sustainability-related financial issues and new financial challenges (e.g., environmental costs).

“University Well-being” and “Expert databases” activities affect the work package. Fair trade (Kim, 2023), sustainable supply chains (Mejía and Manzano et al., 2023), and ethical material sourcing are among the sustainability priorities in the ‘Procurement’ area, which impacts well-being. However, “Food” also addresses sustainable food (Pasquier Merino, 2022) or community garden initiatives (Baur, 2022).

“Activities in open/green spaces” help people understand the emotional and cultural aspects of humanity’s relationship with nature, including art, music, literature, gentle tourism (Rinaldi et al., 2022), basics of natural sciences, knowledge of edible plants, and systematic elements of relevant engineering analyses.

“Morality” is the primary area of activity of “Peace WP” (SDG 16). Here, systemic aspects of the university freedom policy, human rights protection, anti-discrimination efforts, and sustainability policies (with SDG connections) are implemented at the community level. The dominant motives at the individual level are student responsibilities, leadership development, and creating a sustainability identity.

“Performance evaluation” is crucial for system optimization and analyzing the achievement of the established goals. Ensuring comparability in this regard requires a system for rating and evaluating sustainability. Competing in the global university sustainability rankings (Galleli et al., 2022) and winning awards (IGGA 2022) will be beneficial in this activity field.

This work package also aims to strengthen the university’s “Catalyst Role” by developing dissemination activities related to sustainability, performance, best practices, and continuous improvement.

3.2 Economic Sustainability Issues of the University of Sopron

Universities operating in crisis areas, outlying areas, or fiercely competitive environments are those moving toward sustainable management (Lukman–Glavic, 2007; Grecu–Ipina, 2014). These universities also tend to have training structures that guarantee low operational efficiency. Using an alternative to the standard management and maintenance system models is best. Circumstances and opportunities are the result of necessity. These institutions must innovate due to inefficient plant sizes, fierce market competition, and an ardent desire to succeed. Conflicts initially accompany the transition, including institutional crises, multiple conflicts of interest, unexpected turns, and occasional failures. Whether the academic community wins or loses the reform will determine how well the shift to a sustainable management model goes. The short-term success of the previously prosperous developers will depend on the modernization of the university's core operations. It may also be necessary to finance tasks unknown to institutions with large student populations and an economic center. These include basic infrastructure rehabilitation, organizational rationalization, rationalizing space utilization, energy audit, savings strategy, and a renewal plan. Without such interventions, these institutions would be unable to survive independently or in the competitive higher education market. Everyone must support the objectives, necessitating the full leadership of the university's common mindset and practice for successful implementation.

The People & Planet University League (People & Planet, 2015; Jones, 2017), which ranks the environmental and ethical performance of UK universities, cites several criteria that are essential parts of governance reform. Universities can take advantage of the following opportunities for intervention and challenges, supplemented by independent and university-level principles:

- developing environmental policy and strategy
- developing environmental management and audit systems (ISO 2015)
- building a team of experts committed to sustainability
- involving employees and students in the process
- developing an internal legal framework for employees (tasks, powers, responsibilities)
- teaching sustainable development
- developing a carbon emissions strategy
- reducing carbon emissions (ISO 2018)
- using sustainable energy sources (lighting, heating, cooling - combined use of solar energy, geothermal energy, and biomass) (Javed, 2021)
- reducing water use (Pachamuthu, 2021; Li et al., 2022)
- developing SMART measuring systems, building supervision and audit (building, energy, asset protection system (EnergySMART)
- sustainable investments and building structures (development and use of wood and green architecture, capsule house program, autonomous air conditioning program, etc.)
- waste management and recycling (Gherheș et al., 2021; Gulyás and Veres, 2023) (conventional, bio- and e-waste management strategy, industrial by-product from industrial waste, University of Sopron: wood waste management strategy instead of wood by-product strategy)
- sustainable food and packaging materials (Pasquier Merino, 2022)
- sustainable transport strategy (Luttik and Maters, 2022) (car-free zones, electric vehicles, support for cycling and walking)
- developing ethical investment and recovery policies (Pereira and da Silva, 2017) (e.g., Energy Efficiency Obligation Scheme, White Bonds, the market appearance of secondary CO_2 quota)
- optimizing the use of land and space (Abdelalim et al., 2015).

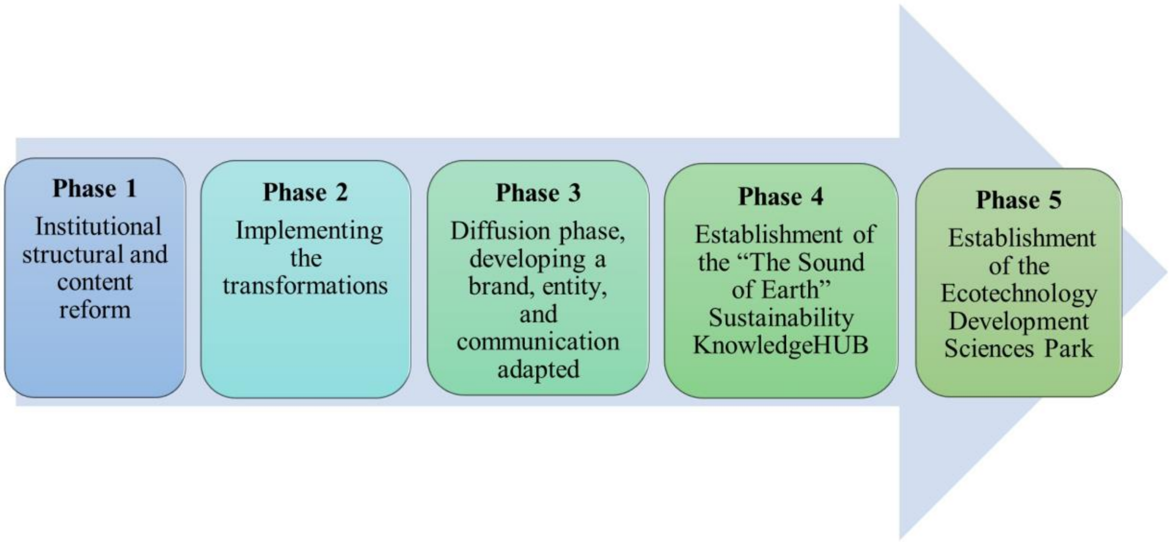

Figure 3. The Sustainable University Management Model of the University of Sopron

The University of Sopron will implement the five phases in the following order (*Figure 3*):

Phase 1: Institutional structural and content reform, space reduction planning, energy modernization planning (health check, designing the new status)

Phase 2: Implementing the transformations, energy, property, and disaster management monitoring system. The "Sound of Earth" implementation program was introduced in Sopron under the SMART UNI program (Berdnikova et al., 2020) and focuses on technical, financial, and professional control systems (energy, material, and equipment flows, supervision and regulation of infrastructure development and operation) and implementing and operating process management and control systems.

Phase 3: Diffusion phase, developing a brand, entity, and communication adapted to the new situation, including educational development, consistent research strategy, organizational development, and communication steps.

Phase 4: Establishment of the "The Sound of Earth" Sustainability KnowledgeHUB to disseminate and market good practices and developments. The management of green initiatives at the university, the operation of accredited measurement and certification systems, knowledge tourism, and the marketing of the resultant assets will all fall under the responsibility of this organization.

Phase 5: Establishment of the Ecotechnology Development Sciences Park at the University of Sopron, into which the Sustainability Knowledge HUB will eventually be integrated.

4 CONCLUSIONS

Sustainability has become a key concept in most areas of life, including science. Universities and their managements must consider environmental, social, and economic dimensions. The University of Sopron has acknowledged this and increasingly emphasizes the implementation of its sustainability strategy.

The coherent, systemic design, implementation, maintenance, and operation of the work packages, activity areas, and system elements presented in the University of Sopron's Sound of the Earth Implementation Program guarantee ongoing sustainability performance improvement. One of the main challenges lies in maintaining a systemic mode of operation, which requires continuous commitment, institutional-level coordination, and sufficient resources, while the university's operational environment – particularly its economic and energy conditions – may change rapidly. The success of the model largely depends on the active engagement of both the leadership and the university community.

The University of Sopron is highly committed to evaluating its sustainability performance. It has ranked in the sustainable world university lists, such as UI GreenMetric, since 2020. The university continuously improves its results. In 2023, we are ranked 130th (near the top 10%) in the worldwide ranking list, 47th among European universities, and third among Hungarian HEIs. The University of Sopron earned 82% of the total score (8,200/10,000 scores) in 2023, an approximately 180% increase in four years, which is unique in Hungary. To maintain its high rankings, the university leadership invested in sustainable infrastructural development, including the construction of a biomass heating plant, the comprehensive development of a waste management system, and the purchase of selective bins and bikes. In our case, the strongest indicator groups are "Energy and Climate Change," "Water management," "Transportation," and "Education and Research." We hold a leading position among Hungarian Universities in these categories.

The goal of the transformation and development is to create an energy- and environment-conscious, innovation-oriented, frugal, efficient, and sustainable university. In this way, not only can it be among the best on international sustainability rankings (Galleli et al., 2022; UI GreenMetric 2023; THE Impact Rankings 2023), which are so important for institutions, but the institution's management becomes sustainable, its resilience to economic and energy crises is strengthened, and its exposure is reduced. Ultimately, its sales potential is also strengthened. The University of Sopron aims to become the Central European innovation center for eco-technology and one of the most sustainable universities in the world.

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Effectiveness of Randomness Tests on Altered Spatial Distribution of Originally Random Trees

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ABSTRACT

This study investigates the sensitivity of five statistical tests (CE, quadrat 3x3, CDF, MAD, and DCLF) in detecting anomalies within originally random tree distributions in forested areas. By simulating tree disappearance due to various anomalies, the effectiveness of these tests is assessed across different tree densities and anomaly magnitudes. Results indicate that the quadrat test and Monte Carlo-based tests (MAD and DCLF) are significantly more sensitive to deviations from randomness than the CE and CDF tests, particularly in denser forests with higher levels of tree disappearance. The findings underline the importance of selecting appropriate statistical tools for analyzing spatial patterns in ecological research.

TANULMÁNY INFÓ

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Térbeli véletlenszerűség
Faeloszlás
Anomália azonosítása
Erdőelemzés

KIVONAT

A véletlen eloszlású fák megváltozott térbeli eloszlását tesztelő próbák hatékonysága. A tanulmány öt statisztikai próba (CE, 3x3-as kvadrát, CDF, MAD és DCLF) érzékenységét vizsgálja eredetileg véletlenszerű fák eloszlásából származó anomáliák kimutatására erdőterületeken. Az eltűnő fák anomáliáit szimulálva a próbák hatékonysága különböző faeloszlási sűrűségek és anomália-mértékek mellett került elemzésre. Az eredmények szerint a kvadrátpróba és a Monte Carlo-alapú tesztek (MAD és DCLF) hatékonyabbak a véletlenszerűségtől való eltérések kimutatására, mint a CE és CDF tesztek, különösen sűrűbb erdőkben és magasabb faeltűnési aránynál. A megállapítások hangsúlyozzák a megfelelő statisztikai módszerek kiválasztásának fontosságát az ökológiai kutatásokban.

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1 INTRODUCTION

Forests are vital ecosystems that significantly contribute to biodiversity, carbon sequestration, and various ecological functions (Luyssaert et al., 2007; Pan et al., 2011). However, these ecosystems face increasing threats from human activities and natural events, leading to anomalies such as illegal logging, tree mortality, and natural disasters (Bugmann et al., 2019; Frazier et al., 2013). Understanding the impacts of these anomalies on forest dynamics is crucial for effective management and conservation (Vanderwel et al., 2013). Recent research has focused on the spatial patterns of trees within forests to assess the impact of disturbances. Point pattern analysis provides a robust framework for evaluating the relationship between tree distribution and random expectations, which may indicate underlying ecological processes (Hengl et al., 2009; "Introduction," 2007; Tóth et al., 2024).

Several statistical tests have been developed in this area, including the Clark-Evans (CE) test (Clark and Evans, 1954), the quadrat test (Hafner, 1992), the Cumulative Distribution Function (CDF) test (Baddeley et al., 2015), the Maximum Absolute Deviation (MAD) test (Bivand et al., 2013), and the Diggle-Cressie-Loosmore-Ford (DCLF) test (Baddeley et al., 2014). The listed tests are non-parametric, which enhances their role in simulation studies compared to parametric tests such as ANOVA since the assumptions of parametric tests, such as normality, are not always met.

These spatial tests provide nuanced insights into the arrangement of trees, elucidating how anomalies impact forest structure. The CE test evaluates clustering or regularity by analyzing nearest-neighbour distances, categorizing spatial patterns as random, clustered, or regular, and aiding in detecting localized anomalies (Szmyt, 2014). The quadrat test assesses density across smaller sub-regions, highlighting spatial heterogeneity by dividing the study area into equal grids (Haase, 1995; "Quadrat Counts," 1981). The CDF and MAD tests further deepen the analysis by examining the empirical distribution of distances between trees, revealing variations in spatial spread and proximity (Law et al., 2009; Wiegand and Moloney, 2015). Finally, the DCLF test detects and quantifies clusters, providing robust insights into the influence of disturbances or environmental stressors on spatial distributions (Cressie, 2015; Loosmore and Ford, 2006). Despite advances in spatial analysis, the effectiveness of statistical tests in detecting anomalies concerning varying tree densities remains insufficiently explored. Recent findings suggest that tree density significantly influences the reliability of these tests in detecting spatial anomalies (Viljur et al., 2022).

This research aims to investigate how different quantities of randomly distributed trees in forest areas affect the ability of various statistical tests to detect anomalies. By analyzing the performance of these tests, the present study seeks to provide new insights into the threshold values at which statistical tests signal deviations from randomness. The simulation involves randomly placing trees and tracking the effects of specific tree removals, with particular attention to the influence of neighbouring trees on spatial patterns. This methodology underscores the importance of proximity in evaluating spatial distributions and highlights how disturbances can impact forest structure and ecological balance (He et al., 2022; "The Homogeneous Poisson Point Process," 2007).

Furthermore, this research not only advances theoretical understanding but also has practical implications for forest management and conservation efforts aimed at mitigating the impacts of anomalies on forest integrity. By enhancing the robustness of statistical tests in detecting anomalies, the findings will inform better practices in forest management, enabling timely interventions that can preserve ecological integrity and support sustainable forestry practices.

2 MATERIALS AND METHODS

2.1 The Methodology of Simulation

During the simulation, eight areas measuring $100x100$ meters were defined, within which $m = (50, 100, \ldots, 400)$ trees were randomly placed. In each forest area, $l = 1, 2, \ldots$, up to a maximum of 20% (specifically $10, 20, \ldots, 80$) of the trees were simulated to disappear. The anomalies associated with tree disappearance were based on the premise that anomalies affecting multiple trees impact the nearest trees to the initial tree (*Figure 1*). The $(k+1)$-th tree affected by an anomaly (where $k \in 1, \ldots, l$) was identified as the tree closest to the previously affected n trees based on the smallest Euclidean distance, calculated as $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$. Every combination of m and l was repeated 50 times to ensure the power of the tests. A total of $18{,}000$ simulations were conducted (specifically $10x50, 20x50$, ..., up to $80x50$).

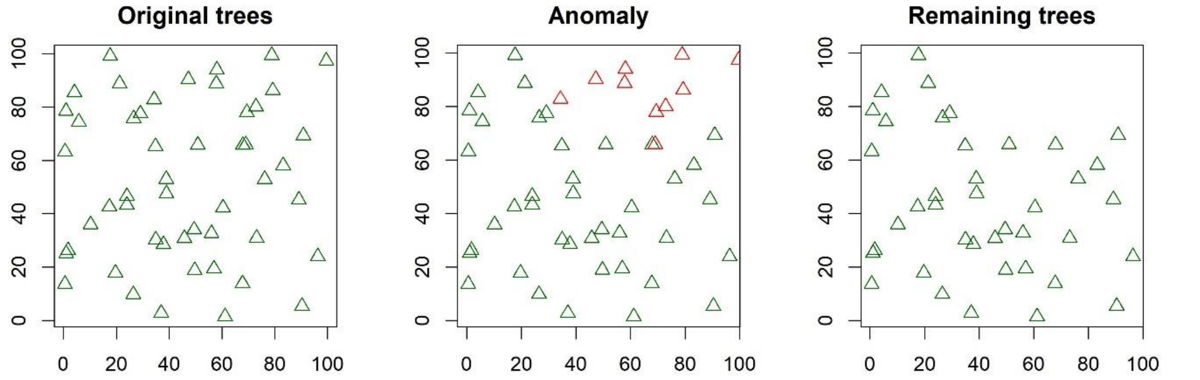

Figure 1. A potential anomaly affecting trees (m=50, l=10)

Edge problems are a general challenge in spatial statistical analyses. Repeated experiments can reduce their impact but cannot entirely eliminate them. Correction techniques associated with the K-statistic – such as edge correction, isotropic correction, and translation correction – are technically straightforward to implement. However, their applicability to different areas and anomalies is not fully resolved. On the one hand, different correction methods typically yield different results, and the specific characteristics of the study area always determine which method should be used. In our case, this is not feasible. On the other hand, due to the bias caused by corrections and the secondary nature of the edge problems in repeated experiments, the literature also advises caution when using edge corrections. (Baddeley et al., 2015) For these reasons, no edge correction was applied in our analysis.

The CE, quadrat (3x3), CDF, MAD, and DCLF tests were performed for each case, focusing on areas without trees affected by anomalies.

The significance level (α) is set to 5% for all tests.

CE test is based on Clark-Evans index, namely

$$R = \frac{\bar{d}}{\mathbb{E}[D]} = \frac{2\sqrt{\bar{\lambda}}}{m} \sum_{i=1}^{m} d_i$$

where m is the number of sampled points, and $\bar{\lambda} = N/|W|$ is the estimated intensity for the complete point pattern comprising N data points within a window W. The value $R = 1$ indicates a completely random pattern, $R > 1$ implies regular spacing, while $R < 1$ indicates clustering.

The CE test is conducted by approximating the distribution of R under CSR (Complete Spatial Randomness) as a normal distribution with a mean of 1 and a variance of $s^2 = (1/\pi - 1/4)/(m\lambda)$, therefore

$$H_0\ (CE): R = 1. \tag{1}$$

The quadrat test is a modified χ^2 test. In this study, the windows were divided into a $3x3$ grid ($q = 9$), which is a common choice, though other configurations can also be used. Considering the total number of points $n = \sum_j n_j$ and the total window area $a = \sum_j a_j$, the estimated intensity can be expressed as $\lambda = n/a$. Consequently, the expected count in quadrat B_j is given by $e_j = \lambda a_j = n a_j/a$. The test statistic is then defined as follows

$$\chi^2 = \sum_j \frac{(obs\ -\ exp)^2}{exp} = \sum_j \frac{\left(n_j - e_j\right)^2}{e_j} = \sum_j \frac{\left(n_j - \bar{\lambda} a_j\right)^2}{\bar{\lambda} a_j}.$$

If all the quadrats possess identical area, then the n_j values are independent and have a uniform expected value under the null hypothesis. Consequently, the test statistic simplifies to

$$\chi^2 = \sum_j \frac{\left(n_j - n/q\right)^2}{n/q}.$$

Under the null hypothesis, the test statistic distribution is approximately a χ^2 distribution with $q - 1$ degrees of freedom. This approximation is typically considered acceptable when the expected counts e_j exceed 5 for all quadrats; however, in areas affected by anomalies where trees have disappeared, it may not always be the case that all counts meet this threshold. Nevertheless, a weaker condition, where approximately 80% of the expected counts exceed 5, is almost certainly satisfied, therefore

$$H_0(Q): n_j \sim Poisson\left(\lambda a_j\right)\ \ \forall j. \tag{2}$$

The CDF test is based on the well-known (and therefore not requiring further elaboration) Kolmogorov-Smirnov test theory, which measures the greatest difference between the empirical CDF (cumulative distribution function) and the specified theoretical CDF. Selecting the covariate as "x" (without specifying an actual covariate) indicates that the covariate corresponds to the Cartesian x-coordinate, represented $Z(x, y) = x$. This approach allows for a direct comparison between the observed and expected distributions of the x-coordinate. This strategy is particularly beneficial for testing the null hypothesis of homogeneity against the alternative hypothesis of a significant large-scale spatial trend, especially in the absence of covariate data, assuming

$$H_0(CDF): F_{obs}(x) = F_{exp}(x)\ \ \forall x \tag{3}$$

where $F_{obs}(x)$ is the observed cumulative distribution function and $F_{exp}(x)$ is the expected cumulative distribution function, indicating that the distributions are homogeneous across the x-coordinate.

Under CSR, the K-function (Ripley, 1979), which is a very sophisticated tool in the examination of homogeneity with the meaning of expected number of points within distance r

of a given point, is expressed as $K_{theo}(r) = \pi r^2$ as the expected value of the K-function. It leads to the more interpretable $L_{theo}(r) = r$ since $L(r) = \sqrt{K(r)/\pi}$. In these cases, the test statistic T can be defined as the maximum absolute deviation between $S(r)$ (representing the CDF of the observed events) and its theoretical counterpart $S_{theo}(r)$ under the null model. This maximum deviation is calculated over the distance range from 0 to R units, where R is a predetermined upper limit on the interaction distance. Therefore,

$$T = \max_{0 \le r \le R} |S(r) - S_{theo}(r)|$$

was selected. Thus, T represents the maximum vertical difference between the graphs of $S(r)$ and $S_{theo}(r)$ across the specified distance range. This method condenses the data into a single value T, known as the maximum absolute deviation (MAD), which is similar to the test statistic used in the Kolmogorov-Smirnov test.

To perform a Monte Carlo test, the observed value t_{obs} of the MAD for the point pattern data is calculated, along with the MAD values $t_1, \dots, t_{nsim}$ for the simulated point patterns, assuming

$$H_0(MAD): K(r) = \pi r^2, L(r) = r \;\; \forall r \in [0, R]. \tag{4}$$

The null hypothesis is rejected if t_{obs} exceeds the maximum $t_{max} = max\{t_1, \dots, t_{nsim}\}$ of the simulated values. This approach constitutes the MAD test with a significance level of $\alpha = 1/(nsim + 1)$. Here, $nsim$ denotes the number of simulated point patterns generated under the assumption of the null hypothesis. In the Monte Carlo tests, with the used $nsim = 19$ (or any other values), the p-values are discrete, taking specific values such as 0 or 0.05 in our case, depending on the proportion of simulations greater than or equal to the observed test statistic.

A more punctual approach to condensing the summary function $S(r)$ into a single numerical value T involves calculating the integrated squared deviation from the theoretical value, namely

$$T = \int_0^R \left(S(r) - S_{theo}(r)\right)^2 dr.$$

The Monte Carlo test using T is commonly referred to DCLF test, as follows

$$H_0(DCLF): S = S_{theo}(R) \;\; \forall r \in [0, R] \tag{5}$$

where the interpretation of the variables remains the same as before. The explanation provided for the previous Monte Carlo test applies here as well.

2.2 The Methodology of analysis

The proportion of p-values for each statistical test (*1-5*) of that are less than or equal to 0.05 for each (m, l) group was computed as *SRR (Significant Result Rate)*. For each combination of m and l, the number of significant results out of 50 experiments were calculated, and the proportion was subsequently visualized. The significant proportions of the five statistical tests were categorized into eight distinct groups based on m, and the relationship between l and the proportion of significant p-values as measurement series was examined (significant result rate).

The Kruskal-Wallis test examines whether the medians of the five measurement series are equal, namely

$$H_0: \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 \tag{6}$$

where η_i represents the median of the i-th measurement series.

The Dunn test performs pairwise comparisons to determine if the medians of any two measurement series are equal, as follows

$$H_0: \eta_i = \eta_j \ \forall i \neq j \tag{7}$$

where η_i and η_j are the medians of the i-th and j-th measurement series, respectively.

3 RESULTS AND DISCUSSION

Thus, a total of $18{,}000$ p-values related to areas were analyzed in the appropriate structure. From a statistical perspective, all m values (with $l = 0$) are likely to represent a random distribution and can indeed be considered *in the field* as such.

For the CE test, the proportion of significant results ($p \leq 0.05$) is 0.068 when $l = 0$, while for the other four tests, it is below 0.05 (ranging from 0.045 to 0.048). Therefore, the CE test appears to be less reliable compared to the other four tests. If the significance level is reduced to 1%, the proportion of significant results ($p \leq \alpha$) becomes 0.017 for the CE test, 0.009 for the Q and CDF tests, and 0 for the MAD and DCLF tests.

The tests differ in their effectiveness regarding the proportion of significant results they produce for actual (real) deviations from randomness ($l > 0$), as evaluated by tests of (*1*-*5*).

Figure 2 visually depicts well-separated groups for larger m and l. In such cases, the values of tests (*2*) and (*4*-*5*) perform better, demonstrating greater sensitivity to actual deviations from randomness – both statistically and visually – compared to the other two tests of (*1*) and (*3*).

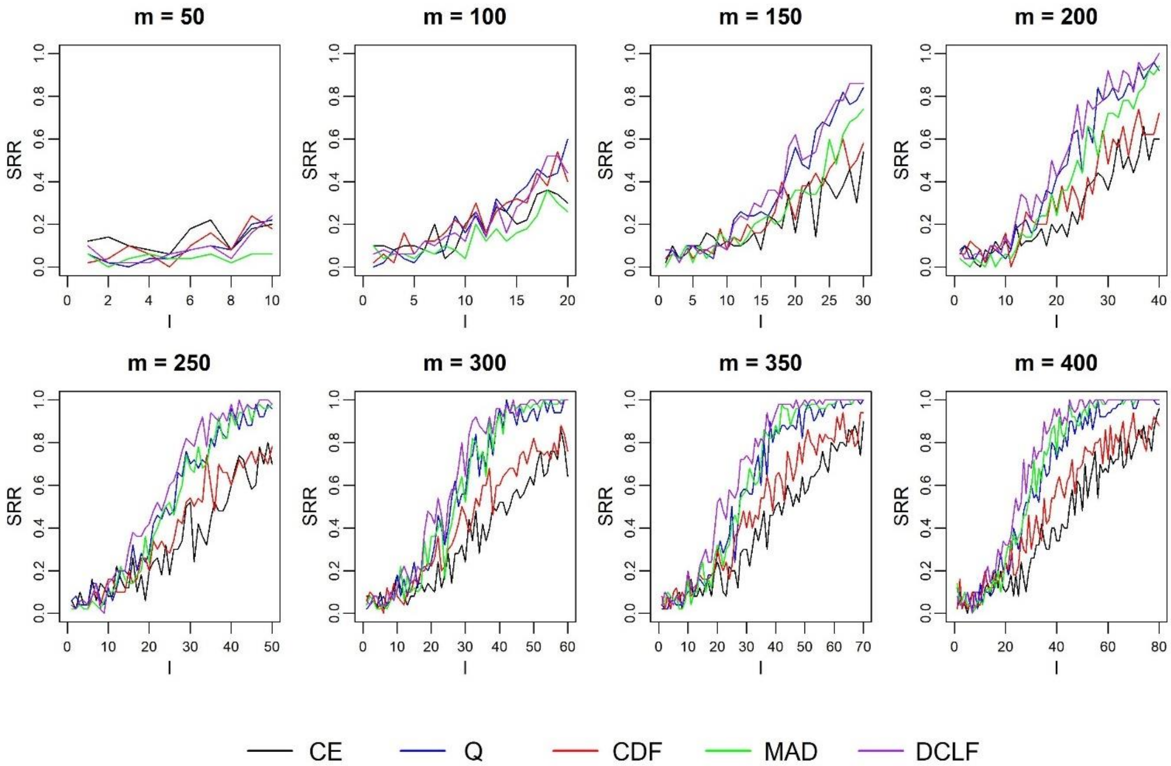

Figure 2. The proportion of significant results for each test under different m and l

Our results based on (*6-7*) confirm the visual impressions and partially refine them further.

The two significant values observed with $m = 50$ are certainly interesting, but given that they emerged under very low SRR, their true relationship is doubted, and a random association is suspected instead. From $m \geq 200$, however, the results become increasingly convincing. Significant outcomes are progressively more apparent (*Table 1*).

It can be concluded that the Q, MAD, and DCLF tests are fundamentally more sensitive to actual deviations from random spatial distribution. However, no significant differences are observed between these tests.

The CE and CDF tests performed significantly worse than the ones listed above, but no significant differences were observed between them in terms of SRR. It is worth noting that despite their relatively lower sensitivity, these tests also yielded satisfactory results at high m and l values. The insensitivity of the CE along the y-axis further reduces the already limited general applicability of the CE method.

The main conclusion is that in a relatively dense forest, the statistical detection of anomalies affecting a relatively large number of trees can be most efficiently carried out using the Q test and the two Monte Carlo-based tests (MAD and DCLF).

Table 1. Values of p from (6-7)

Test		m							
		50	100	150	200	250	300	350	400
Kruskal-Wallis		**0.021**	0.361	0.223	**0.034**	**0.004**	**<1e-3**	**<1e-3**	**<1e-3**
Dunn	CDF-CE	0.841	1.000	1.000	1.000	1.000	1.000	0.541	0.647
	CDF-DCLF	1.000	1.000	1.000	0.358	0.055	**0.009**	**0.001**	**<1e-3**
	CE-DCLF	0.391	1.000	0.517	**0.041**	**0.007**	**<1e-3**	**<1e-3**	**<1e-3**
	CDF-MAD	0.439	0.533	0.925	0.709	0.574	0.172	0.066	**0.005**
	CE-MAD	**0.008**	1.000	1.000	1.000	0.187	**0.008**	**<1e-3**	**<1e-3**
	DCLF-MAD	0.858	1.000	1.000	0.716	0.974	0.615	0.434	0.573
	CDF-Q	1.000	1.000	1.000	0.960	0.400	0.191	0.228	0.054
	CE-Q	0.424	0.956	0.692	0.208	0.107	**0.010**	**0.006**	**0.001**
	DCLF-Q	0.988	1.000	1.000	1.000	1.000	0.769	0.302	0.252
	MAD-Q	0.706	1.000	1.000	1.000	0.797	0.909	0.587	0.427

Not every forest area contains trees following a random pattern. However, many non-random distributions can be virtually converted into random ones, for instance, by repositioning trees or planting new ones. Following new tree identification processes, such as aerial, UAV, or field surveys, the original pattern is often not reconstructible with meter-level precision. Nonetheless, the random nature of a genuinely random tree distribution generally remains unchanged. Using the same conversion, even inherently non-random distributions can be transformed into random ones after a new survey and identification process.

If an anomaly involving tree disappearance has occurred in certain areas, some tests can detect it with considerable sensitivity. One might ask why a previously identified tree distribution is not compared directly with a newer one that only reflects the remaining trees. The answer is straightforward as mentioned previously: it is typically impossible to detect two identical distributions with exact precision across different surveys of the same area using UAV or other tools, except through highly complex and non-generalizable methods. However, the randomness, regularity, or clustering characteristics of trees in a given area only change due to a significant external impact (Baddeley et al., 2015).

This article fundamentally focuses on randomness or the process of reducing distributions to randomness. However, the generalization of other types of distributions can also be of significant importance.

For the sake of reproducibility of the research results, the associated R codes have been made available (Tóth, 2024).

4 CONCLUSIONS

The study of random distributions and deviations from randomness is highly beneficial in forestry for several reasons. Random patterns often serve as a baseline for understanding natural tree distributions in undisturbed ecosystems. By comparing actual distributions to a random baseline, foresters can identify anomalies caused by factors such as disease, pest infestations, illegal logging, or natural disasters.

Detecting deviations from randomness also aids in monitoring ecosystem health. For instance, clustering patterns may indicate localized disturbances or areas of higher soil fertility, while regular patterns might suggest human intervention, such as plantation forestry. Additionally, understanding random distributions supports better forest management by providing a reference for assessing regeneration success and habitat suitability for wildlife.

Moreover, anomaly detection can be crucial for early warning systems, allowing timely responses to issues affecting forest sustainability. In reforestation efforts, ensuring random-like planting patterns can enhance biodiversity and resilience to environmental changes. These applications make the analysis of randomness a valuable tool in both research and practical forestry management. Changes or anomalies detected in the random tree distributions within individual forest areas are best analyzed using the quadrat, MAD, and DCLF tests, though the CE and CDF tests may also be suitable.

Among the three well-performing tests that show no significant differences in performance, any of them could theoretically be suitable for developing an anomaly-detection algorithm. However, the quadrat test appears to be the most practical choice. The MAD and DCLF tests, which are based on the Monte Carlo method, are extremely computationally and resource-intensive. While these tests might be preferable for scientifically rigorous investigations, the quadrat test emerges as an efficient and fast method for routine applications. Naturally, all tests can provide increasingly accurate results with appropriate parameters, but under generally accepted settings, this conclusion can be drawn.

Building on the experiences with the methods, it is worth examining more specific cases in the future, using even larger real or generated samples.

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Species Seasonal Development of the *Ulmus* L. Genus in the Right-Bank Forest-Steppe of Ukraine and Features of Shoot Growth During the Vegetation Period

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ABSTRACT

This study examined the features of the phenological phases in four *Ulmus* L. genus species by conducting phenological observations at the educational and production department of the Uman National University Bilohrudivskyi Forest, from 2022 to 2024, using accepted methods. The timing of the seasonal development phases in the *Ulmus* genus species corresponds with the phenological seasons, determined by natural and climatic parameters. A single-peaked curve with a peak from the first decade of May to the second decade of July characterizes indicators of shoot growth dynamics. Shoots of *Ulmus* L. grew to 77–83% of their total length by the end of July during the growing season before adding another 17–21% in August, indicating that, despite temperature variations, the studied species fully adapts to the research region conditions.

TANULMÁNY INFÓ

Kulcsszavak:
Fenológiai megfigyelések
Hőmérséklet-változások
Dinamika

KIVONAT

Az *Ulmus* L. faj szezonális fejlődése. nemzetség fejlődésének alakulása a jobb parti erdőssztyeppéken Ukrajnában, és a hajtásnövekedés jellemzői a vegetációs időszakban. Az erdészetben és a kertészetben széles körben használt négy *Ulmus* L. nemzetségfaj fenológiai fázisainak jellemzőit vizsgálták. A fenológiai megfigyeléseket 2022-2024 folyamán az Umani Nemzeti Kertészeti Egyetem Bilohrudivskij erdőben található oktatási és termelési részlegén végezték az általánosan elfogadott módszerek szerint, és megállapították, hogy az *Ulmus* nemzetség fajaiban a szezonális fejlődési fázisok időzítése megfelel a fenológiai évszakoknak, amelyeket a természeti és éghajlati paraméterek alapján határoznak meg. A hajtásnövekedés dinamikájának mutatóit egycsúcsú görbe jellemzi, amelynek csúcspontja a május első dekádjától július második dekádjáig tartó időszakban van, amikor a legintenzívebb növekedésük következik be. Július végén az Ulmus hajtáshossza eléri a vegetációs időszak alatti teljes hosszának 77-83%-át. Ez azt jelenti, hogy a vizsgált fajok a hőmérséklet-ingadozások ellenére teljes mértékben alkalmazkodtak a kutatási régió körülményeihez, és aktívan be lehet őket vezetni a kultúrába. Augusztusban a hajtások 17-21%-kal nőnek.

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1 INTRODUCTION

Research on plant growth and development patterns, coupled with the analysis of accumulated information during cultivation, is vital, both scientifically and practically. Plant seasonal development is particularly significant, especially in the context of the phylogeny process, as an adaptation to specific seasonal changes in climatic conditions (Batsaikhan et al., 2020). Lifecycle rhythms of a single species in different plantings and areas depend on botanical, geographical, phytocoenological, and environmental conditions (Antnova et al., 2019). The species phenorhythm of the genus occurs in such a way that the maximum development of plants occurs during a favorable period of the vegetation season. Endogenous and exogenous factors, including genetic characteristics and environmental conditions of the cultivation area, influence phenological development (Gordo–Sanz, 2010).

The dynamics of growth processes in woody plants change rapidly during seasonal changes (Solla et al., 2005; Uchendu et al., 2013; Välimäki et al., 2021). Consequently, their phenological development is defined as seasonal. Seasonal phenomena and their calendar dates of occurrence, which are inconstant, characterize each territory (Antonova et al., 2019, 2020, 2021).

A certain dependence between climatic factors (particularly changes in air temperature) and the annual plant development cycles has been revealed in recent decades. Scientists have noted several indicators whose seasonal development was sensitive to climate change (Chen, 1995; Menzel – Fabian, 1999). In addition, it was noted that the climate region has an impact on the timing of certain phenological phases (Schwartz, 1996). For example, Chen and Xu (2012) found that there is a greater phase dependence on temperature in milder areas than in harsher climates.

Similar studies of the seasonal development dynamics of certain plants in Europe and North America in temperate and Mediterranean climates have shown close to timely and successful development of all phases in plants without much delay (Bradley et al., 1999;; Menzel and Fabian, 1999; Beaubien and Freeland, 2000; Defila and Clot, 2001; Zhao and Schwartz, 2003; Gordo and Sanz, 2009; Myking and Skrøppa, 2007; Cruz et al., 2021). Such studies have not been conducted in the conditions of the Right-Bank Forest-Steppe of Ukraine.

The phenological phases of woody plants are indicators of climatic conditions. Observing them allows us to track tree responses to warming or precipitation changes and how species adapt to such conditions. Shifts in phenophases indicate climate change, which may help predict how global warming affects the growing season durations and ecosystem resources. *Ulmus* phenological growth patterns aid in the preparation of regional seasonal calendars for forestry. Such calendars are also used in the organization of environmental protection measures and pest and disease control of *Ulmus* species.

2 MATERIALS AND METHODS

Phenological observations of vegetative organ development of the *Ulmus* genus species (*U. laevis, U. glabra, U. pumila,* and *U. minor)* were conducted on the territory of the educational and production department of the Uman National University of Horticulture, Bilohrudivskyi Forest, during 2022–2024 (*Figure 1*). Uniform temperature conditions characterize the entire territory of Ukraine. Therefore, we assume that the obtained results will be similar in all regions of the country.

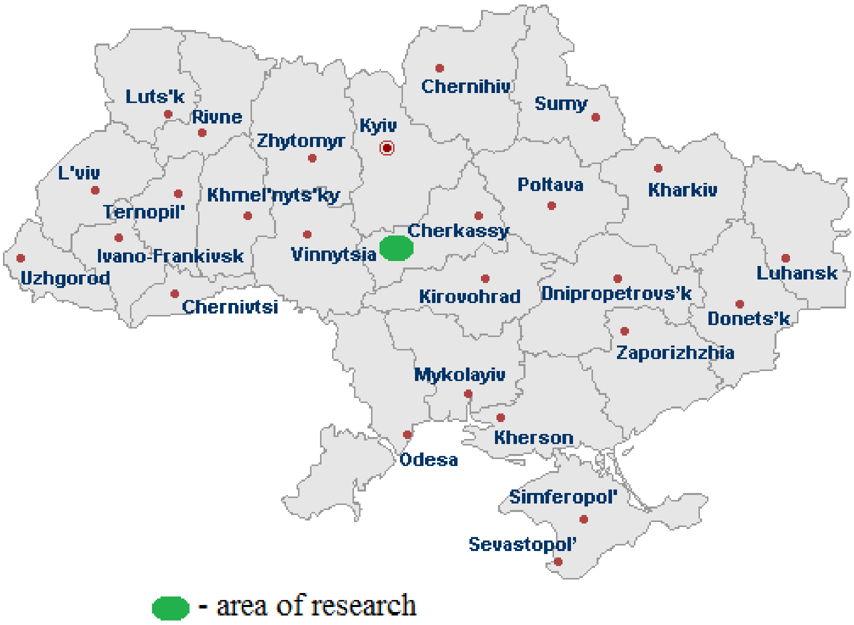

Figure 1. Map of Ukraine with the location of the research sites marked

All plants used for phenological observations grow in similar environmental conditions. The weather station is two to three kilometers from the research site.

We selected trees aged 20–30 years for our research. The height of the trees ranged from 10 to 15 m, and the trunk diameter ranged from 12 to 24 cm. The crown diameter ranged from 4 to 9 m.

Phenological observations of the generative and vegetative organs formation were conducted in 2022–2024 according to the method of Kalinichenko (2000) and Santini et al. (2004).

We conducted the research during the growing season and inspected the plots every two to four days for this purpose. Records were collected of the dates of the certain phenophase of each species under study. We selected ten trees of each species of the same age and size. The shoots from these trees were selected randomly from the middle of the crown.

Shoot growth characteristics during the growing season were found according to the Molchanov and Smirnov method (1967). Data was collected from the bud attachment point to the shoot of the previous year. Shoot lengths were measured with a metal ruler three days after the onset of the linear shoot growth phase. Data from the unfolded leaf attachment from the previous year's shoot was collected. The total number of shoots in each model group was 20 pcs. Daily gains were calculated after shoots stopped growing. Daily gains were defined as the difference in length between the next and the earlier values of each measurement period, divided by the number of days of this period. Measurements were performed following three days of intense growth and during the five days of decline afterwards. We recorded the average daily air temperature throughout this time. According to the study results, schedules of shoot growth during the vegetative season and of growth dynamics were drawn. The schedules recorded the dependence of shoot growth intensity on air temperature.

Observations followed model trees of different ages that had reached reproductive capacity. Phenological observations were conducted during the period of physiological activity. Observations were completed only once or twice a week in the summer when development is inhibited.

Based on the research results, we constructed graphs depicting shoot growth during the vegetation period. We established the growth dynamics and shoot growth intensity dependency on air temperature. Examining shoot growth duration and shoot growth dynamics is vital to determining the winter hardiness of plants because shoots that finish growing early tend to be winter resistant, but slower-growing shoots can also achieve such resistance.

Statistical processing of the research results was performed with Excel. We calculated the Spearman rank correlation using Spearman's correlation coefficient, a nonparametric method that estimates the strength and direction of a monotonic (increasing or decreasing) relationship between two variables. Unlike Pearson's coefficient, Spearman's does not require normal data distribution. The calculation is based on the ranks of values in each variable, rather than on the numerical values themselves. We calculated Kendall's tau with the R program.

A temperate continental climate with warm and soft winters characterizes the research region. According to the Uman meteorological station, the average long-term air temperature is +7.2°C, with the coldest month (January) being minus 5.8°C and the hottest month (July) being 19.7°C. The average absolute minimum air temperature is -21°C. Extreme frosts are rare. The average daily temperature steadily exceeds +5°C in the first decade of April and +10°C in the third. The period with an average daily temperature above +10°C continues for 160–165 days. The duration of sunshine per year is 840 hours and 460–520 hours during the vegetation period. The average sum of daily temperatures above 0°C is 3155°C, +5°C - 3040°C, and +10°C - 2710°C. The weather is warm initially in the summer before turning hot in July and August.

The beginning of spring (steady transition of the average daily air temperature through 0°C) starts on March 15–20 (*Table 1*). However, late and early springs do occur.

Table 1. Average monthly temperature (°C) for 2022–2024 (according to the Uman weather station)

Year	Month												Year's average
	1	2	3	4	5	6	7	8	9	10	11	12	
2022	-4.7	0.5	4.5	9.6	17.0	23.4	20.0	20.7	15.6	10.0	5.5	2.2	10.4
2023	0.4	2.2	6.3	9.2	12.5	20.9	21.6	21.2	17.8	12.7	3.7	0.0	10.7
2024	-2.3	-3.8	2.0	7.4	14.0	19.8	23.2	20.3	13.0	7.2	4.7	1.3	8.9
Mean	-2.5	-0.4	4.3	8.7	14.5	21.3	21.6	20.7	15.4	9.9	4.6	1.2	9.9
Long-term mean	-5.7	-4.2	0.4	8.5	14.6	17.6	19.0	18.2	13.6	7.6	2.1	-2.4	7.4

Table 1 shows that the research years are characterized by slightly higher temperature values for individual months compared to the average long-term data. Frequent dry periods with air temperatures above 35 °C in the shade mark the spring and summer period. The annual mean air temperature over the years of investigation was +9.9 °C with a maximum of +29.9 °C (August 15, 2023).

3 RESULTS

The vegetation of the studied species begins when the maximum average monthly temperature reaches +17°C or above, the average daily temperature is in the range of +4.2 to 6.6°C, and the minimum is -2.0°C to 5.2°C.

The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 4) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27–April 4) and continued for 10–12 days. The bud swelling phase was simultaneously observed in the latest of the Ulmus species in our research, *U. pumila* and *U. minor* (March 29–April 4) and lasted 11–18 days (*Table 2*).

Table 2. The dates of shoot and leaf development in species of the genus Ulmus in Uman, 2022 –2024

Species	year	Vegetative organs development date								
		Buds and shoots				Leaves				
		bud swelling	bud opening	start of shoots linear growth	end of shoot linear growth	leaf emergence starts	complete leaf emergence	leaf discoloration	falling leaves	leaf fall end
U. pumila	2022	12.04	24.04	03.05	26.08	28.04	01.08	02.10	16.10	19.10
	2023	15.04	23.04	01.05	01.09	26.04	09.08	36.09	13.10	16.10
	2024	30.03	20.04	29.04	23.08	26.04	03.08	28.10	01.11	14.11
U. glabra	2022	31.03	18.04	26.04	23.08	25.04	30.07	25.09	05.10	12.10
	2023	07.04	21.04	30.04	30.08	01.05	05.08	18.10	22.10	30.10
	2024	27.03	15.04	24.04	25.08	22.04	28.08	18.10	23.10	30.10
U. laevis	2022	03.04	12.04	21.04	21.08	23.04	30.07	28.09	02.10	11.10
	2023	10.04	19.04	28.04	27.08	23.04	03.08	12.10	20.10	29.10
	2024	23.03	11.04	20.04	17.08	19.04	28.07	15.10	26.10	02.11
U. minor	2022	08.04	21.04	01.05	25.08	25.04	27.07	03.10	17.10	19.10
	2023	13.04	23.04	04.05	03.09	29.04	03.08	17.10	28.10	13.11
	2024	29.03	17.04	25.04	20.08	21.04	25.07	26.10	28.10	05.11

Budding began in the second to third decade of April during the research years on species and forms of the genus Ulmus. The earliest budding was seen in *U. laevis* (April 11–April 19), which lasted 7–9 days. The latest among the studied species was in *U. pumila* (April 20–April 24) and *U. minor* (April 17–April 24).

The linear shoot growth started the earliest in *U. laevis* (20.04–28.04) and *U. glabra* (March 24–April 30). The phase of linear growth occurs 4–9 days later in *U. pumila* and 6–10 days in *U. minor* than in *U. laevis*. Shoot growth completion was noted when the last leaves were finished expanding.

The change in leaf color was most clearly seen in *U. laevis* (September 28–October 23). Under favorable conditions, the color change occurred in the third decade of September and the second decade of October in other Ulmus species. The consistently warm autumn of 2023 delayed the discoloration and leaf fall phase, which occurred 15–20 days later than in 2021 and 2022. The life processes in plants are inhibited after leaf fall, and they enter a dormant state.

Research on seasonal shoot growth of species and forms of the genus *Ulmus* indicates that the conditions of the Right-Bank Forest-Steppe of Ukraine induce a growth period of 86 to 127 days. Growth process lengths depend on the biological characteristics of the species.

The linear growth of shoots in all representatives of the genus *Ulmus* began at the same time, at the beginning of the third decade of April.

During all the research years, the shoot growth of *U. laevis* was observed from the transition of the budding phase at the end of the second and beginning of the third decade of April on average (*Figure 2*).

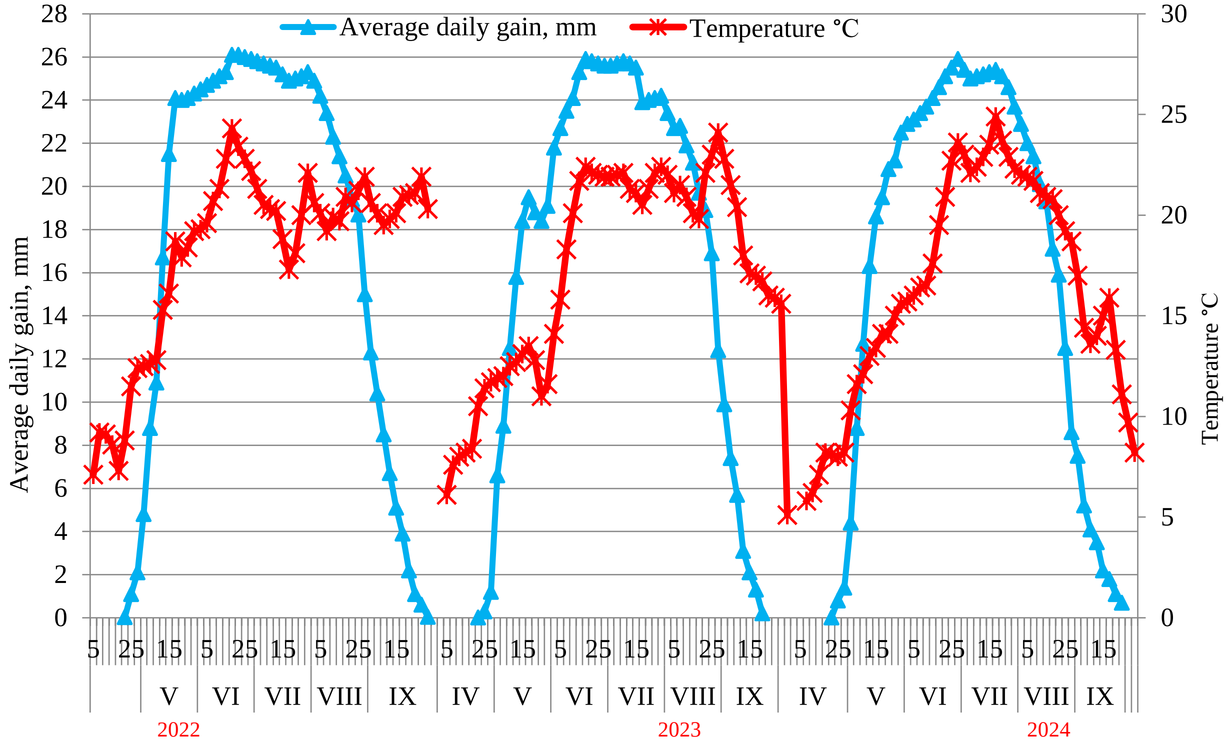

Figure 2. Seasonal growth dynamics of U. laevis during 2022–2024

The budding phase transition occurred when the average daily temperature exceeded +11.5°C in 2022 and 2023. Shoot growth was observable at temperatures above +8°C during the slightly colder spring of 2024. Furthermore, daily shoot growth intensified as the temperature increased. The culmination of the species shoot growth for all years varied by dates but occurred in mid-June and was 25.9–26.1 mm per day. For example, there was a rapid increase in temperature to +23– 24°C in the second decade of June 2022, which caused an average daily growth of 26 mm per day. Then, the growth intensity gradually decreased as the temperature dropped. July 2024 recorded a significant increase in temperatures above +24°C, which was higher than in June.

According to the research, *U. glabra* begins vegetation at the same time as U. laevis on a 3-year average and is dependent on air temperature to some degree (*Figure 3*).

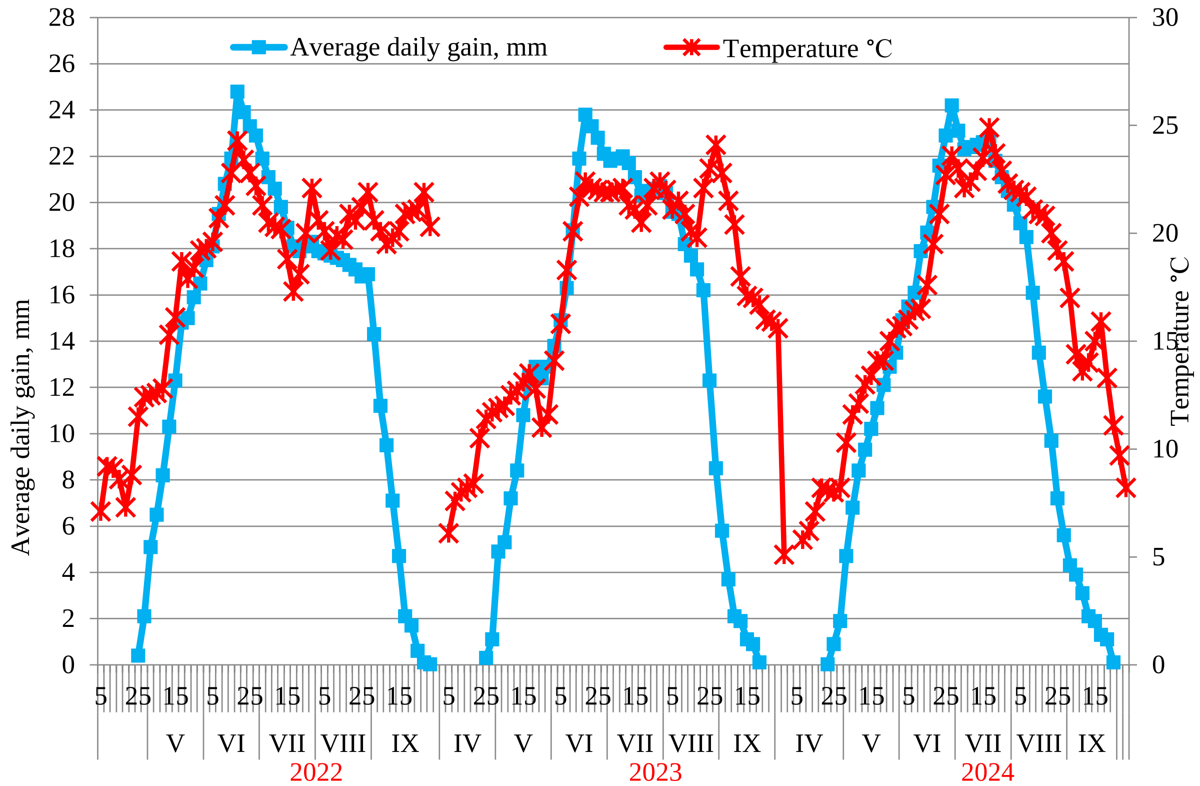

Figure 3. Seasonal growth dynamics of U. glabra in 2022–2024

Compared to the species above, *U. glabra* has slightly lower average daily growth value and intensity values. However, it has a rather clear dependence on temperature variations at the beginning of shoot growth and before culmination, so the maximum growth value matches the maximum temperatures of this period. The growth value for *U. glabra* is 23.1–24.2 mm per day, except for 2024 when the highest air temperature for the season was recorded in the second or third decade of August, and growth intensity had already begun to decline. However, there was a slight jump in growth. For this reason, the correlation coefficient here was 0.79, the highest for all years. There were frequent, rapid increases and decreases in temperature by several degrees starting in the third decade of August 2022; however, this had no significant impact on shoot growth during the growing season. The correlation coefficient, which in this case was 0.73, confirmed this. As for 2023, the highest temperature for the season (+24.1°C) was observed at the end of the third decade of August, when the shoots were nearly grown and preparing for dormancy. Therefore, it did not affect growth.

U. pumila starts vegetation 4–6 days later than the previously-mentioned species and has a lower shoot growth rate (*Figure 4*).

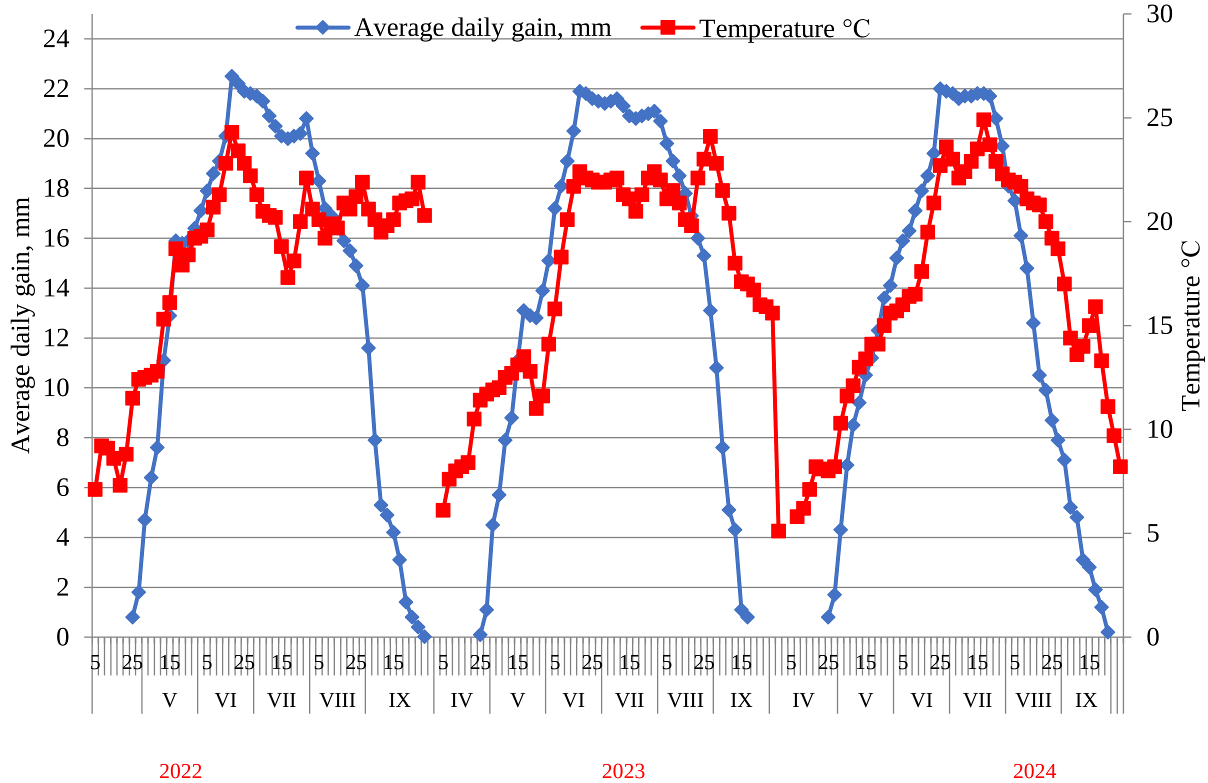

Figure 4. Dynamics of seasonal growth of U. pumila during 2022–2024

U. glabra had a shoot growth length of 24.2 mm at the culmination. For *U. laevis*, this figure was 26.1 mm, while for *U. pumila* it was 22.2 mm.

Thus, *U. pumila* showed a greater dependence of growth intensity on temperature changes. The graphs clearly show that after the shoot growth culminated in June, a second wave of growth was seen when the temperature increased in a specific period. In 2022, this was observed in the second decade of July, when a rapid rise in temperature above 21°C caused a short-term jump in growth to 21 mm per day. In 2023, from the first decade of June to mid-July, the air temperature was the same (except for the last days of the first decade of July). This contributed to the fact that the shoot growth curve was also stable during this period. However, the elevated temperatures of September did not affect growth. In 2024, the highest temperature was recorded in the third decade of June (+23.6°C) and in the second decade of July (+24.9°C). In both cases, there was a jump in growth intensity, up to 21.9 mm and 21.8 mm, respectively.

U. minor shoots start growing slightly later than *U. pumila* shoots. In general, these two species begin growing simultaneously with a difference of several days (*Figure 5*).

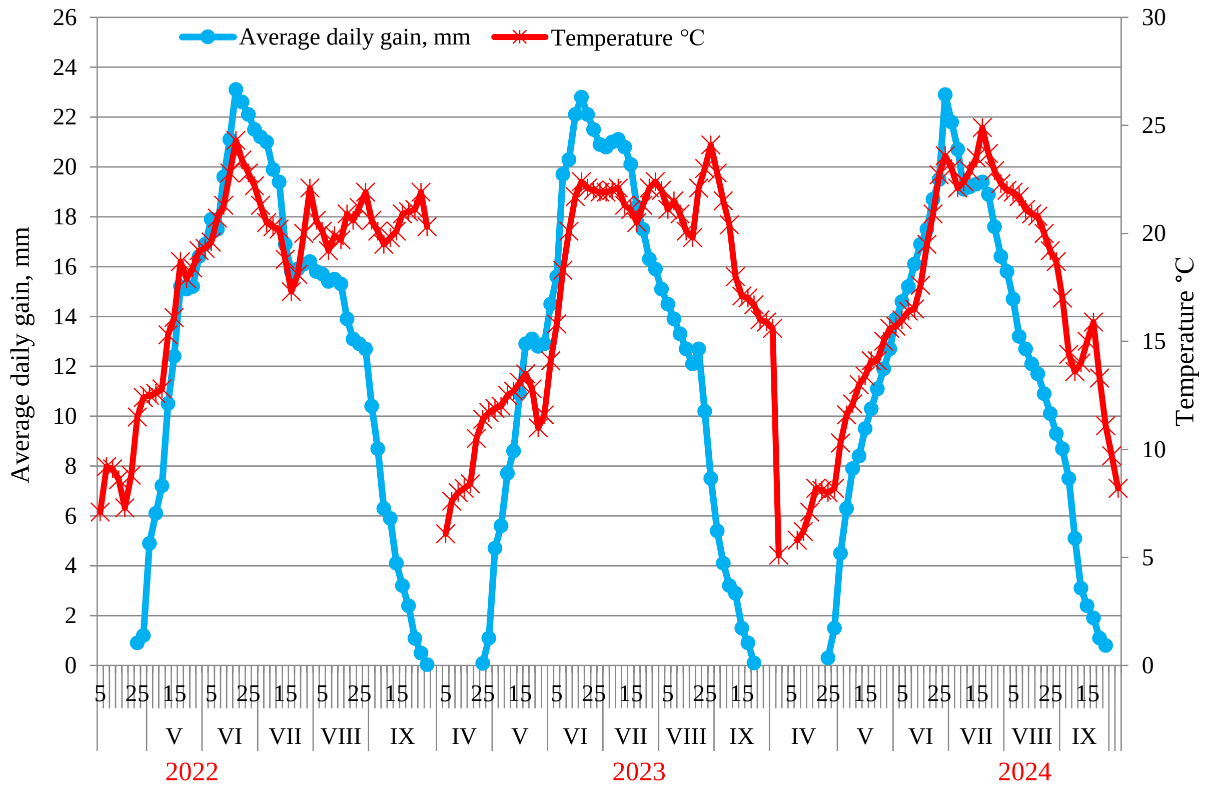

Figure 5. Seasonal growth dynamics of U. minor in 2022–2024

U minor shoots showed a weak reaction to temperature changes at the beginning of their growth. Their average daily growth ranged between 4 and7 mm and began to increase more intensively at a temperature of +13–15°C. Shoot growth was uniformly steady despite some temperature changes. A rapid increase in the average daily growth and the subsequent culmination of the temperature occurred in the first and second decades of June and matched the maximum air temperature during this period. At that time, the growth rate of this species was 22.5 mm per day. After that, growth intensity declined with different dynamics over the years. For example, starting in the second decade of June 2022, the temperature dropped by several degrees, and the drop in growth was quite clearly accompanied by the same dynamics. From the second decade of August, temperature changes of 1–2°C began to occur; however, growth intensity was steadily declining. The temperature in the second to third decade of June 2023 did not show such rapid changes, and we can see a smooth increase in growth. This contrasts with 2024, where the increase in air temperature after the culmination had almost no effect on shoot growth.

During the statistical processing of the data, we determined the coefficient of determination, which measures the dependence of dependent variables (different species growth) on the variation of independent variables (temperature) (*Table 3*).

The statistical data reveal a moderate positive relationship: as the temperature rises, the tendency for shoot growth increases. The probability of such a relationship occurring by chance is extremely low, indicating that the result is statistically significant. The data presented denotes a stable monotonic relationship between temperature and growth. The strength of the correlation increases slightly from 2022 to 2024 for all species, showing a strengthening of the linear dependence. Kendall's τ coefficient has marginally lower values but confirms a stable rank (monotonic) dependence.

Table 3. General statistical analysis of the dependence of shoot growth on temperature during the growing season, 2022-2024.

Year	Species	Statistical analyses			
		Kendall's τ	p-value (τ)	Spearman's ρ	p-value (ρ)
2022	*U. pumila*	0.437	<0.001	0.557	<0.001
	U. glabra	0.483	<0.001	0.611	<0.001
	U. laevis	0.415	<0.001	0.543	<0.001
	U. minor	0.447	<0.001	0.567	<0.001
2023	*U. pumila*	0.426	<0.001	0.548	<0.001
	U. glabra	0.472	<0.001	0.609	<0.001
	U. laevis	0.421	<0.001	0.556	<0.001
	U. minor	0.458	<0.001	0.571	<0.001
2024	*U. pumila*	0.468	<0.001	0.648	<0.001
	U. glabra	0.501	<0.001	0.701	<0.001
	U. laevis	0.436	<0.001	0.589	<0.001
	U. minor	0.474	<0.001	0.617	<0.001

If we characterize the dependencies of shoot growth for each species separately, we can see that *Ulmus pumila* is characterized by a stable, moderately strong positive correlation in all the study years. However, in 2024, the correlation significantly increased (especially r = 0.883), showing a strong linear dependence of shoot growth on temperature. The same applies to *Ulmus glabra*.

Unlike the species described above, *Ulmus laevis* had a moderate dependence in 2022–2023, which intensified in 2024 (r = 0.827). In contrast, *Ulmus minor* had a consistently strong positive correlation throughout all years.

4. DISCUSSION

The timing of the onset of the seasonal development phases in *Ulmus* species corresponds to the phenological seasons, which are distinguished on the basis of natural and climatic parameters (Puzrina – Yavny, 2020). Seasonal rhythms comparison of the *Ulmus* species development showed that they are not significantly different. In general, the onset of phenological phases in the studied species was parallel. The research results on phenological rhythms of development in *Ulmus* species in another region of Ukraine nearly coincide with ours (Stupak, 2024). The shoot growth phase is particularly significant. After all, how long shoots grow depends on the lignification level and, thus, on frost resistance and winter hardiness.

The unexplained variance was the influence of other climatic factors. However, a significant percentage remained for other influencing factors, which is a reason to consider such influences in further research. Weather conditions have a notable impact on the onset of phenological phases. Earlier studies on the dependence of budding and the sum of some temperatures have been conducted (Cannell – Smith, 1983; Murray et al., 1989; Hunter – Lechowitz, 1992; Välimäki et al., 2022).

Some research suggests that temperatures of the previous growth season cause changes in the onset of phenological phases (Chmielewski – Rötzer, 2001; Menzel, 2003; Gordo – Sanz, 2010) and applies to both the early spring and late autumn vegetation (Menzel, 2003; Matsumoto et al., 2003; Gordo – Sanz, 2010). However, other factors such as daylight hours, precipitation, humidity, and even wind strength are thought to influence the end of the growing season in autumn (Chen – Xu, 2012; Hwa et al., 2021). In addition, plants must undergo a dormant state; otherwise, they will not start growing even under favorable temperature conditions (Wareing, 1956; Nitsch, 1957; Vegis, 1964; Välimäki et al., 2022).

The favorable weather conditions in 2022 induced the onset of phenological phases 3–9 days earlier than in 2023 and 2024. Indicators of seasonal dynamics reflect the adaptive features of the studied species to the growing conditions.

The onset of the phenological phases varies significantly by year. For example, the beginning of leaf budding to complete swelling takes 9 to 18 days. Significant temperature changes help explain this trend, under which shoot development accelerated and slowed down. The growth rate of annual vegetative shoots varied over the entire period. The most significant growth in the species studied occurred up to the second decade of July. After that, the growth processes slowed down significantly. The annual shoot growth indicators are related to the sample ages on which the measurements were made. This parameter is 6.5–7 higher in three-year-old plants than it is in 70-year-old plants. Twelve-year-old plants displayed parameters that were 4.5–5 times higher than in 70-year-old plants.

The difference in shoot growth intensity in adult and young plants is explained by the fact that young seedlings use nutrients only for shoot growth and development, while older ones form generative organs. Early termination of shoot growth in adult plants contributes to better wood maturation and, compared to young individuals, to better adaptation to autumn and winter temperature drops. The largest increase over the research years was seen from the third decade of April to the second decade of July. Thus, *Ulmus* shoots reached 77–83% of their total growth during the growing season by the end of July. *Ulmus* species have only one main growth wave, after the culmination of which the growth rate decreases significantly, despite temperature changes. Starting from the second decade of August, growth begins to decline intensively. At this time, the shoots grew by 17% and 21%. In September, shoot growth decreased to 3% of the total growth during the growing season. In the second decade of September, an increase in temperature above +15°C did not affect growth intensity, because the shoots were already preparing for wintering.

The maximum shoot growth intensity in adults of the studied species and forms of the genus *Ulmus* was recorded in the first half of the growing season. In our opinion, such dynamics of annual vegetative shoots growth and their duration explain the high winter resistance of *Ulmus* species because an early completion of growth processes (early budding, more complete lignification of annual shoots, and wood ripening) causes the appropriate time for the decline of growth processes at the cellular level. This characteristic of growth processes contributed to the timely shoot lignification of *Ulmus* species and forms.

5 CONCLUSIONS

The vegetation of the researched species begins in the third decade of April. The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 10) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27– April 7) and was 10–12 days. In the *Ulmus species* that proved to be the latest, the bud swelling phase occurred simultaneously in *U. pumila* and *U. minor* (March 29–April 4) and continued for 11–18 days. The duration of a particular phenological phase in elms is closely related to weather conditions. Calculating the determination coefficients showed that temperature and other climatic factors influence plant growth and development. Indicators of shoot growth dynamics are characterized by a single-peaked curve with a peak in the period from the first decade of May to the second decade of July, when the most intensive growth occurs. *Ulmus* shoot lengths reach 77–83% of their total length during the growing season at the end of July. The shoots grow by 17%–21% in August, indicating that the studied species are fully adapted to the conditions of the research region and can be actively introduced into culture despite temperature variations.

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Comparative Air Flow Analysis Between Johor and Szombathely: Evaluating Woodcarving Ventilation Panels

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ABSTRACT

This study explores the potential of using woodcarving ventilation panels to enhance natural ventilation (NV) in buildings, particularly in extreme climate conditions in two different locations: Johor, Malaysia, and Szombathely, Hungary. The main aim is to assess how these panels contribute to airflow dynamics and temperature regulation within buildings. The research employs Computational Fluid Dynamics (CFD) simulations to model airflow and temperature distribution in identical building models subjected to high wind speeds and temperatures, simulating worst-case scenarios. The findings reveal that while Johor experiences moderate wind speeds resulting in steady but less dynamic airflow, Szombathely benefits from stronger winds, producing more effective ventilation and cooling. These results suggest that woodcarving panels can improve airflow and thermal comfort but are more effective in areas with higher wind speeds. The study concludes that while NV is beneficial, integrating HVAC systems is essential for maintaining optimal comfort in extreme conditions.

TANULMÁNY INFÓ

Kulcsszavak:
Fafaragásos táblák
Természetes szellőzés
CFD szimulációk
Légáram dinamikája
Hőkomfort

KIVONAT

Johor és Szombathely szélviszonyainak összehasonlító elemzése: fafaragásos szellőzőablak táblák értékelése. Jelen tanulmány a fafaragásos szellőzőablak táblák természetes szellőzés fokozásában betöltött szerepét vizsgálja szélsőséges klimatikus körülmények mellett két különböző helyszínen: Johor, Malajzia és Szombathely, Magyarország. Azt vizsgáljuk, hogy mennyire járulhatnak hozzá az ilyen táblák a légáramok dinamikájához és a hőmérséklet szabályozásához az épületen belül. A kutatás során a Numerikus Folyadék Dinamika módszerét használtuk a légáram és hőmérsékleteloszlás modellezésére a legrosszabb esetnek megfelelő magas környező hőmérsékleti és szélsebességi viszonyok azonos kialakítású épületekre való alkalmazásával. Megállapítottuk, hogy míg Johor esetében a jellemző mérsékelt szélsebesség stabil, de kevéssé dinamikus légáramokat eredményez, Szombathely előnyt élvez a hatékonyabb szellőzést és hűtő hatást eredményező erősebb széljárásból. Az elemzés eredményei arra utalnak, hogy a fafaragásos táblák javíthatják a belső légáramokat és a hőkomfortot, de hatékonyságuk a magasabb szélsebességű helyszíneken érvényesül. A tanulmány fő következtetése, hogy míg a szellőzőablak táblák nyújtotta természetes szellőzés értékelendő, szükséges lehet fűtő-szellőző és légkondicionáló (HVAC) rendszerrel való integrálása az optimális komfortérzet fenntartására extrém körülmények között is.

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1 INTRODUCTION

Natural ventilation (NV) has long been a fundamental strategy in vernacular architecture, particularly in tropical and temperate climates, to enhance indoor thermal comfort and reduce reliance on mechanical cooling systems (Abdul Rahim and Szabó, 2023). Across cultures, traditional ventilation methods, such as woodcarving ventilation panels, have been employed to facilitate airflow while preserving aesthetic and cultural identity (Abdul Rahim – Kovács, 2024; Muhammad – Rosdi, 2023; Yusof et al., 2020). Traditional designs often incorporate NV strategies, such as cross ventilation and wind catchers, which enhance thermal comfort and air quality (Michael et al., 2014; Pan et al., 2024). In Malaysia, the intricate woodcarving panels of traditional Malay houses intensify passive cooling. These panels allow air to flow freely while maintaining privacy and aesthetic value, playing a crucial role in optimising indoor thermal conditions (Tong et al., 2024). While woodcarving elements are prominent in Malaysian architecture, similar decorative wooden structures exist in Hungarian heritage architecture, such as the Székely gate, which is primarily constructed from wood, showcasing traditional craftsmanship that emphasises organic architecture principles (Jeffrey, 1995). However, these Hungarian structures primarily serve symbolic and ornamental purposes rather than ventilation. The design of these gates reflects traditional craftsmanship, serving as ornamental features that enhance the aesthetic appeal of rural architecture (Preda et al., 2018). Inspired by the functional use of woodcarving panels in Malay architecture, this research explores their potential integration into Hungarian housing to improve NV in temperate climates.

Previous studies highlighted the role of woodcarving ventilation panels in optimising NV in tropical climates. Traditional Malay houses utilise NV to achieve thermal comfort, with optimal indoor temperatures ranging from 25°C to 27°C (Alkausar – Riyani, 2023; Nik Hassin – Misni, 2023). In contrast, Hungarian vernacular architecture has been studied mainly for its thermal insulation properties rather than NV. The use of heavy materials, such as brick or stone, helps to absorb heat during the day and release it at night, maintaining a stable indoor temperature (Sood, 2023). Comparative studies of NV across different climatic regions have been conducted, concluding that regional climate conditions significantly influence the efficiency of passive ventilation strategies. In arid and semi-arid regions, cross-ventilation with opposing windows significantly improves NV rates, achieving substantial energy savings. Windcatchers further enhance ventilation and reduce cooling demand (Ayoobi et al., 2024). They are effective in improving air quality and reducing energy consumption for air conditioning in tropical climates, even with slight temperature differences between indoor and outdoor spaces (Bernal et al., 2024). Additionally, with climate change causing higher summer temperatures in Hungary, the need for improved passive ventilation solutions has become increasingly important (Fürtön et al., 2022). However, no direct comparison has been made between NV performance in Malaysia and Hungary using the woodcarving ventilation system.

This study presents a comparative simulation of NV performance through traditional woodcarving ventilation panels in two distinct climatic zones, tropical Johor Bahru, Malaysia, and temperate Szombathely, Hungary. By integrating cultural woodcarving designs into ventilation strategies and analysing airflow performance through transient CFD simulations, this research bridges architectural heritage with environmental performance. The novelty lies in applying traditional woodcarving ventilation in both local and foreign contexts and evaluating its effects under real summer weather conditions. This cross-cultural and cross-climatic analysis offers new insights into how culturally significant designs can be adapted for contemporary passive ventilation strategies across diverse regions.

2 MATERIALS AND METHODS

This study employed CFD simulations to analyse the effectiveness of woodcarving ventilation panels in enhancing NV in two distinct climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The methodology consists of computational modelling and simulation analysis. To evaluate thermal comfort in the studied buildings, we used the ASHRAE 55 standard (2020) as the primary guideline for determining acceptable comfort conditions. According to this standard, thermal comfort is influenced by factors such as temperature, humidity, and air velocity (Agrawal and Tiwari, 2010; Olesen and Brager, 2004). To assess the adequacy of passive airflow, we measured indoor temperatures, relative humidity, and air velocity across the room.

2.1 Computational Modelling

The floor plan in *Figure 1* features an 11m x 6m floor plan with a 3.5m ceiling height designed to optimise NV. Two human figures are positioned to simulate thermal comfort—one between the living and kitchen areas and another in the bedroom. The floor plan includes multiple rooms, seven windows, and ten woodcarving ventilation panels, such as those above the main entrance and bathroom shown in *Figure 2*. These panels integrate traditional motifs, enhancing airflow and preserving cultural significance. The open interior doors mimic typical usage, further promoting air circulation. This setup enables the analysis of how woodcarving elements affect airflow and thermal comfort in modern architecture.

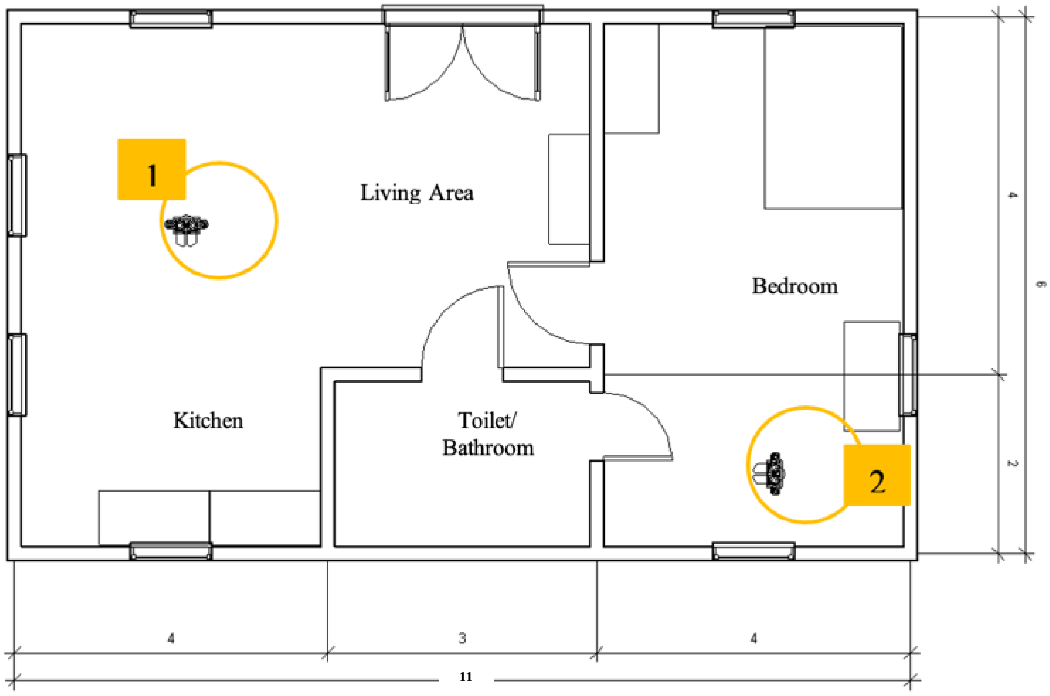


Figure 1. Floor plan

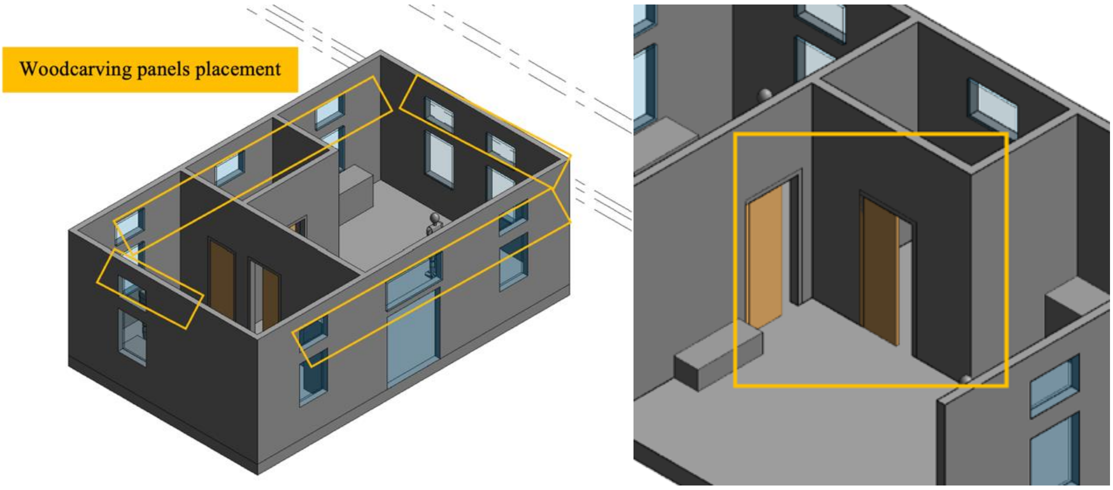


Figure 2. Woodcarving placements and interior doors' position

The woodcarving designs from Rumah Limas Hutan Bandar MBJB and Székely Gate motifs were implemented as ventilation panels in the CFD models for the Johor and Szombathely simulations. These 3D models demonstrate how traditional woodcarvings, such as the *ukiran kerawang tebuk tembus* and *Ketumbit* flower motifs from Rumah Limas and the *kaputükör* design from Székely gates, can be integrated into modern architecture. The carvings, categorised by their void-to-total area ratios, were scaled to fit the building openings in Autodesk Revit to ensure consistency in panel sizes for the simulations.

Table 1. Woodcarving ventilation panels placement.

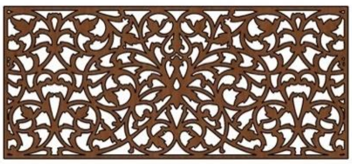
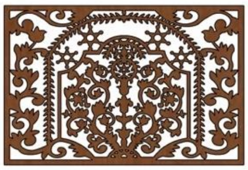
Location	Code	Panel	Description
Above the windows & toilet wall	WC1		• QTY: 8 Nos • 609.6 mm x 914.4 mm
Above the main entrance	WC2		• QTY: 1Nos • 800 mm x 1800 mm
Above the windows & toilet wall	WC3		• QTY: 8 Nos • Size: 609.6 mm x 914.4 mm
Above the main entrance	WC4		• QTY: 1 Nos • Size: 800 mm x 1800 mm

Table 1 shows the woodcarving panels (WC1, WC2) placed above windows and the bathroom wall, with one larger panel above the main entrance in the Johor situation. In

Szombathely, similar arrangements were made, with panels (WC3 and WC4) located above windows, the bathroom wall, and the main entrance. These panels, varying in size from 609.6 mm x 914.4 mm to 800 mm x 1800 mm, were chosen for their ability to enhance ventilation while preserving cultural motifs. This integration facilitates NV while contributing to the aesthetic and cultural significance of the designs.

2.2 Simulation Setup

Following Autodesk tutorial guidelines, an external air volume extending beyond the building geometry - three times the building height and five to six times the width and depth - was defined for the CFD simulations to ensure accurate airflow modelling without boundary interference. This volume, with dimensions of 12891 cm in height, 34126 cm in width, and 67000 cm in depth, was positioned at an angle of -22.5° to simulate real-world wind conditions, as shown in *Figure 3*. Materials were also assigned to the building geometry.

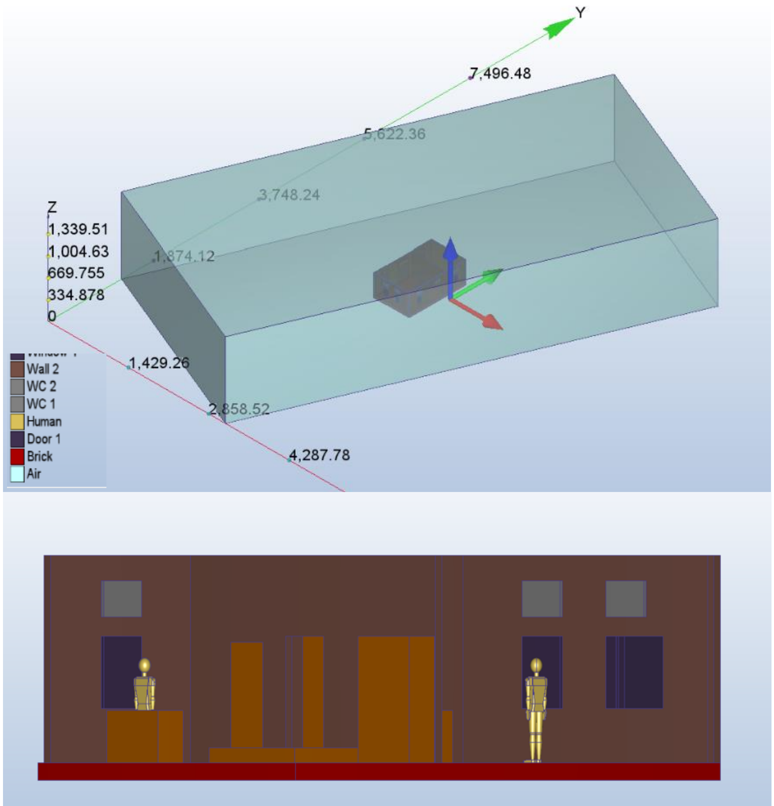


Figure 3. Geometry setup on CFD Autodesk

CFD simulations were conducted under steady-state conditions using the following boundary conditions to replicate real-world climate conditions in Johor, Malaysia, and Szombathely, Hungary. The materials used for the buildings in each location were updated to ensure accurate thermal performance and airflow simulations, considering the specific climate conditions of both regions.

The wind speeds of 7 m/s (for Johor) and 14 m/s (for Szombathely), as shown in *Table 2*, represent the highest recorded values during the selected days, 28–29 July 2022, for both Johor and Szombathely. These values were chosen to simulate peak environmental stress during extreme conditions. For Johor, the data were obtained during a site visit at Rumah Limas Hutan Bandar MBJB. For Szombathely, the weather data were extracted from the Energy Plus Weather (EPW) file corresponding to the same dates. While such high wind speeds are not typical of average summer conditions (e.g., Szombathely's summer average is ~2.5 m/s), they were intentionally used to assess the robustness of NV under boundary conditions that may occur during rare but impactful climatic events.

Table 2. Boundary conditions for Johor and Szombathely

Boundary condition	Value (Johor)	Value (Szombathely)	Surface/Volume
Temperature	32°C	34°C	South (Johor) & North-Northwest facing (Szombathely) external air volume
Velocity	7 m/s	14m/s	South (Johor) & North-Northwest facing (Szombathely) external air volume to simulate wind flow
Pressure	0 Pa	0 Pa	North (Johor) & South-Southeast facing (Szombathely) external air volume, acting as the outlet.
Film coefficient	20 W/m²K	20 W/m²K	Entire outer surface of the building
Human	60 W/m²K	60 W/m²K	Two human figures positioned within the building to assess thermal comfort

The building materials for both regions were modified as detailed in *Table 3*. These materials represent typical components found in Malaysian and Hungarian buildings, ensuring realistic thermal simulations.

Table 3. Materials for both buildings

Material	Johor Building	Szombathely Building
Walls	Material: hardwood, thermal conductivity: 0.16 W/mK	Material: Brickwork thermal insulation, eq. thermal conductivity: 0.065 W/mK
Windows	Default CFD	Material: Window (solar), Thermal conductivity: 0.2 W/mK
Entrance door	Default CFD	Material: Window (solar), Thermal conductivity: 0.23 W/mK

Woodcarving Panel Representation: The woodcarving panels used in the simulation presented a challenge due to their complex geometry, which could not be directly imported into Autodesk CFD. To address this, a Free Area Ratio (FAR) was calculated for each panel to represent airflow resistance. The FAR was used to define the panels as resistive boundaries, enabling an accurate representation of their influence on airflow.

The FAR was calculated using the formula: $FAR = \frac{\textbf{Open Area}}{\textbf{Total Area}}\ x\ 100$

This ratio is crucial for assessing a panel’s potential to enhance NV. Panels with a higher FAR, such as WC3 and WC4, are more effective in promoting airflow, while WC1 and WC2 provide a balance between structural integrity and ventilation. While FAR is a widely used static indicator to estimate the potential for NV, its applicability under high wind speeds must be interpreted with caution. At elevated wind velocities, airflow behaviour is influenced not only by the size of the openings but also by pressure distributions, turbulence, and vortex formation. Therefore, FAR in this study serves as an initial comparative metric of panel openness rather than a definitive predictor of ventilation efficiency. The CFD simulations provide a dynamic understanding that complements FAR by capturing real airflow phenomena such as jetting, separation, and recirculation that FAR alone cannot represent (*Table 4*).

Table 4. Free area ratio

Woodcarving Panel	FAR
WC1	0.4314 or 43.14%
WC2	0.3773 or 37.73%
WC3	0.4657 or 46.57%
WC4	0.4485 or 44.85%

3 RESULTS

This section presents a detailed analysis of the CFD simulation results for airflow and temperature distribution in two different climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The simulations focus on the effectiveness of woodcarving ventilation panels under extreme conditions. Identical building models were used for both regions to ensure a consistent basis for comparison.

3.1 Airflow Distribution and Velocity Magnitude

Figure 4 illustrates the air circulation pattern in the Johor case study. The airflow pattern in the figure shows a combination of smooth directional flow and localised circulation. Air enters the building through openings, creating a generally consistent horizontal flow across most rooms. In certain areas, especially near corners and around partitions, the vectors curve and form swirling patterns, indicating vortex formation and recirculating zones. These vortices suggest reduced airflow efficiency in those regions. The direction and density of the streamlines also show how air is guided by the room layout, with some zones experiencing faster, more concentrated flow, particularly along narrow paths between openings. *Figure 5* illustrates the airflow distribution inside the building, with wind velocities ranging from 0 to 3.5 m/s in (a) and 0 to 2 m/s in (b) Johor. These velocities fall within the range considered beneficial for NV according to ASHRAE 55, which notes that air speeds up to around 0.8 m/s are generally comfortable for occupants under warm conditions, and higher speeds may enhance thermal comfort through convective cooling. However, excessively high speeds may lead to discomfort due to drafts. The variation in velocity indicates the dynamic nature of airflow through different parts of the building, with higher velocities potentially improving heat dissipation and indoor air quality, especially in open-plan spaces or near openings. In the figures, the visibility of red colour was used to indicate areas with the highest wind speeds or velocities, providing a clear visual reference for airflow intensity across the interior space.

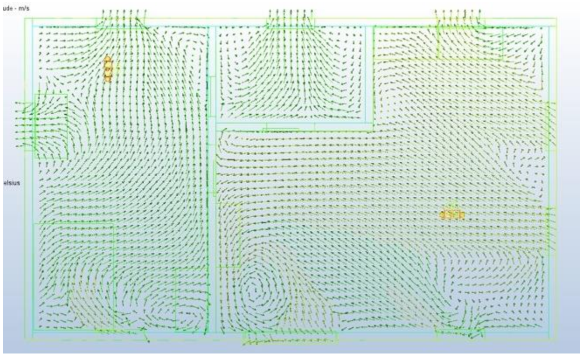
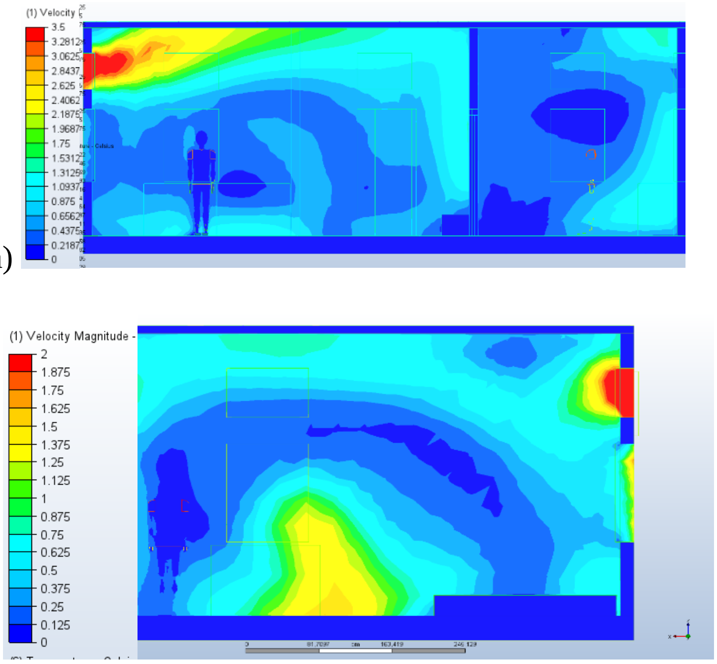


Figure 4. Overall air circulation in Johor

(a)



(b)

Figure 5. Overall air velocity distribution in Johor

In Szombathely, *Figure 6* illustrates the airflow pattern, which reveals a more directional and intensified flow, especially on the right-hand side of the building. The vector lines in this region are denser and more aligned, indicating strong, uninterrupted airflow, likely due to favourable wind entry and exit paths. In contrast, the left side of the building exhibits more dispersed and slower airflow, with several vortices and recirculation zones forming in corners and near walls. These circular patterns indicate areas where air movement is less effective, possibly leading to stagnant zones or uneven ventilation. *Figure 7* experiences stronger winds, causing airflow velocities of 0 to 5 m/s inside the building, as shown in (a) and 0 to 2.5 m/s in (b). The dynamic airflow is characterised by higher velocities and turbulence. The stronger winds enable greater exchange of indoor and outdoor air, which enhances NV and provides more cooling and better temperature regulation. Higher air velocities, especially when occupants have some control over their environment, can significantly improve thermal comfort by increasing convective heat loss. In this case, the stronger winds facilitate a greater exchange of indoor and outdoor air, thereby enhancing NV effectiveness and inducing better temperature regulation and cooling, which is particularly beneficial in hot and humid climates. Nonetheless, areas experiencing wind speeds near or above 5 m/s should be carefully evaluated to avoid discomfort from drafts.

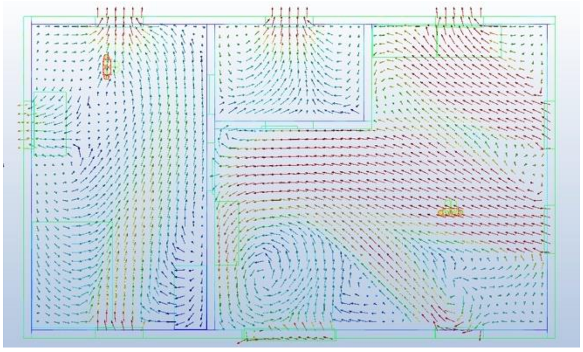


Figure 6. Overall air circulation in Szombathely

(a)
(b)

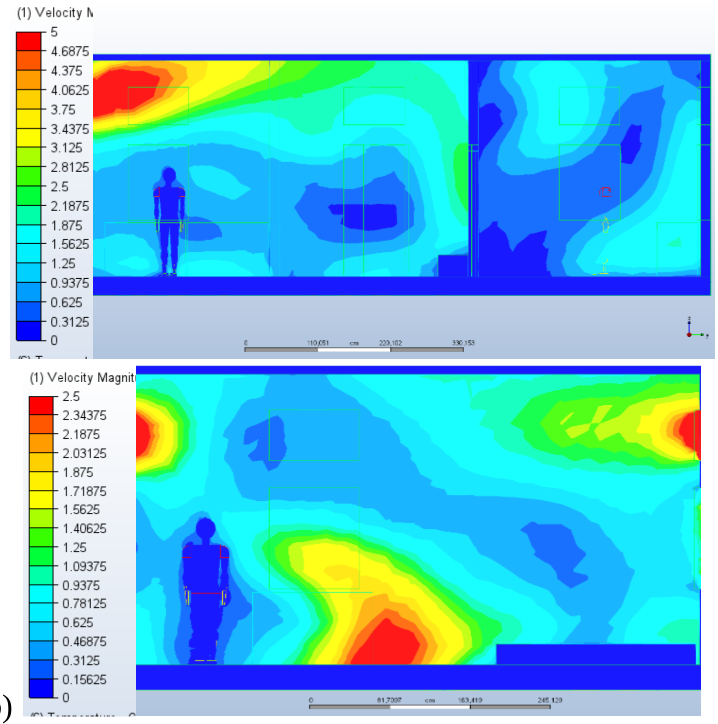


Figure 7. Overall air velocity distribution in Szombathely

The graph in *Figure 9* compares the velocity magnitude (m/s) against the distance from Point A to Point B, shown in *Figure 8*. In Johor, the airflow velocity remains low and steady, below 1 m/s for most of the distance. In Szombathely, the airflow starts higher (around 2.5 m/s) and remains consistently higher, indicating more efficient ventilation and cooling, especially during extreme temperatures.

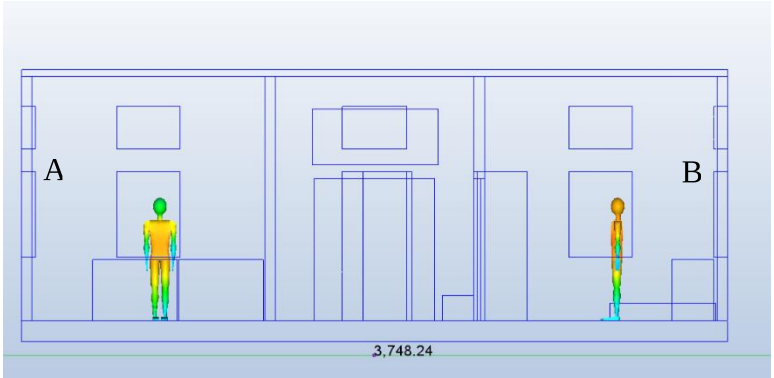


Figure 8. Point A and Point B plotting

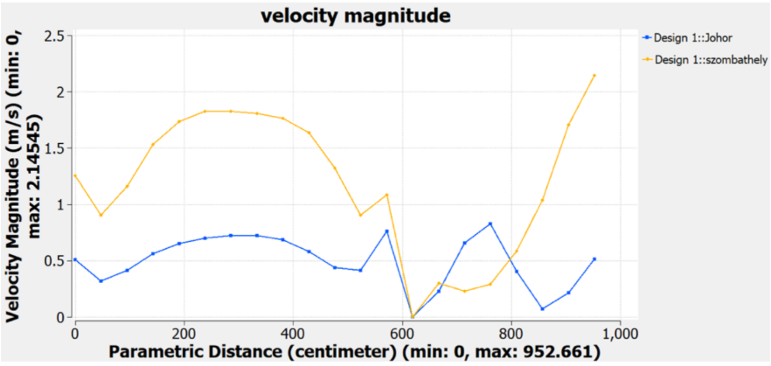


Figure 9. Change of velocity magnitude along the path from point A to B

3.2 Flow Dynamics and Air Circulation

Figure 10 and *Figure 11* provide velocity vector representations of the airflow dynamics. In Johor, wind velocities range from 0 to 0.6 m/s around the human figures, suggesting a steady but moderate airflow. In Szombathely, the airflow around the two human figures ranges from 0 to 2 m/s, indicating a more dynamic circulation and better penetration of airflow throughout the building. The increased wind speeds in Szombathely lead to more effective cooling and improved thermal comfort compared to Johor, where moderate wind speeds result in more stable but less dynamic airflow.

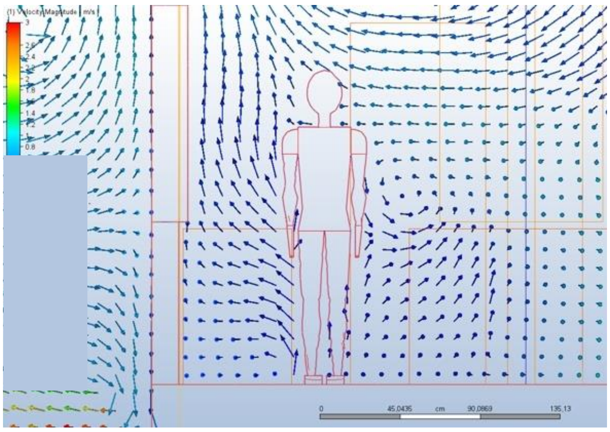


Figure 10. Air circulation near human figures in Johor

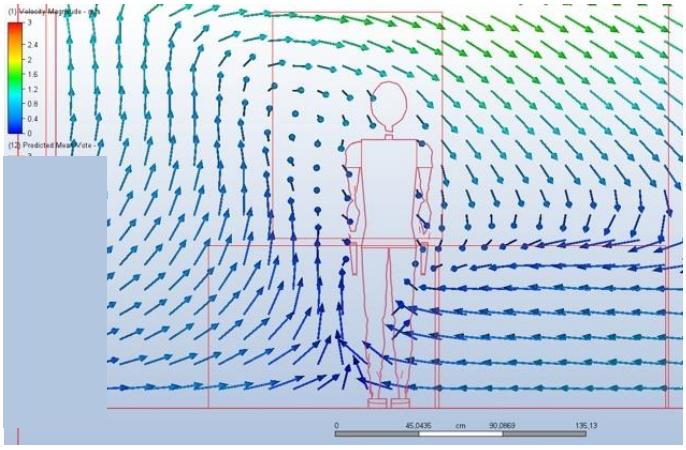


Figure 11. Wind circulation near the human figure in Szombathely

While the woodcarving ventilation panels help improve airflow and passive cooling in both Johor and Szombathely, the extreme temperatures in both locations remain a significant challenge to achieving optimal thermal comfort. Passive ventilation alone may not be sufficient to address these extreme conditions. Integrating HVAC systems can help supplement passive cooling by providing active cooling and dehumidification. In Johor, HVAC systems can enhance cooling during the hottest months, while in Szombathely, they can help maintain comfortable indoor temperatures during high outdoor temperatures, supporting the effectiveness of the NV system.

4 DISCUSSION

The integration of passive NV, particularly through traditional woodcarving elements, plays a significant role in maintaining thermal comfort in buildings (Jay et al., 2023; Nugroho, 2024), especially in climates with moderate temperatures. However, as observed in the Johor and Szombathely case studies, passive airflow alone does not suffice to maintain optimal comfort in conditions where the indoor temperature exceeds 34°C, which falls outside the acceptable range defined by ASHRAE Standard 55 for naturally ventilated spaces. This highlights the limitation of relying solely on passive design strategies in both tropical and temperate climates (Alkausar – Riyani, 2023).

Although high wind speeds are generally beneficial for NV, this study treats the combination of high wind speed and high temperature as a worst-case scenario for thermal comfort due to potential draft discomfort and elevated heat gains in extreme conditions. This can cause sensations such as discomfort from still, humid air or excessive draft, depending on airflow direction and velocity. By connecting airflow performance to user sensations as described in ASHRAE 55, such as air movement acceptability and occupant satisfaction, a fuller picture of the thermal experience emerges (Candido – Dear, 2012). Moreover, the interaction between airflow and characteristics and human comfort is complex. Factors such as airflow velocity, turbulence, and the spatial arrangement of ventilation openings significantly influence user perceptions of comfort (Sholanke et al., 2022). For example, in areas where airflow is inadequate or overly turbulent, occupants may experience discomfort in the form of stickiness, draft discomfort, or lack of cooling, which detracts from the intended benefits of NV. Therefore, a more detailed understanding of how these airflow characteristics are perceived by occupants is necessary for optimising NV systems in future designs.

Beyond thermal comfort, the use of traditional woodcarving for ventilation serves both cultural and functional roles (Haoming – Chen, 2014; Ayowembun – Arifin, 2024). From a modern user's perspective, the aesthetic value of these features can be preserved while improving thermal performance. This balance between tradition and comfort is crucial for integrating heritage elements into contemporary sustainable architecture.

5 CONCLUSIONS

This study concludes that passive ventilation using traditional woodcarving panels is insufficient to maintain thermal comfort as defined by ASHRAE standard 55, particularly during periods of extreme summer heat in both study regions. A hybrid strategy combining HVAC systems with traditional architectural elements is therefore recommended to achieve comfort standards. Importantly, the refinement of traditional elements should not only focus on preserving cultural identity but also on enhancing performance. Integrating modern design tools and engineering principles can improve airflow delivery and contribute to occupant well-being while retaining the symbolic and historical essence of traditional craftsmanship (Laine et al., 2000; Lyckov, 2024). In conclusion, the effective integration of traditional and modern systems offers a promising path toward designing spaces that respect cultural heritage while meeting the thermal and comfort needs of contemporary users. This approach can help create more sustainable, culturally sensitive and comfortable living environments, both for the present and future generations.

6 FUTURE CONSIDERATIONS

The integration of traditional design elements with modern HVAC systems offers a promising area for further research. Future studies could explore how traditional architecture can be future-proofed by combining eco-friendly HVAC solutions with local materials, ensuring both sustainability and thermal comfort. Consider the broader implications of cultural heritage preservation in modern-day buildings and propose further research into efficient solutions that balance cultural identity with comfort.

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Environmental Attitudes of Firewood Users in Hungary: Contradictions of Knowledge and Emotions

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ABSTRACT

This study examines environmental attitudes toward the production and utilization of firewood. A telephone survey using a structured questionnaire was conducted. The survey yielded 603 usable responses, and the analysis revealed that firewood users exhibited strong support for two fundamental environmental concepts: the notion that harvesting firewood from healthy trees is acceptable and the assertion that firewood is, in principle, carbon-neutral. However, a significant proportion of respondents also expressed concerns that firewood use may potentially contribute to forest degradation and increase climate change. To further explore these attitudes, respondents were categorized into three distinct groups. A statistical analysis revealed significant differences among these groups in educational attainment and standard of living. Attitudes towards complex environmental issues are predominantly influenced by emotions that reflect general environmental concerns due to the public's limited knowledge base, which hinders factual assessments.

TANULMÁNY INFÓ

Kulcsszavak:
Szolgáltatások fenntarthatósága
Körforgásos gazdaság
Karbonsemleges
Szénciklus
Éghajlatváltozás
Fa tüzelőanyag
Fatüzelés

KIVONAT

A tűzifát használók környezeti attitűdje Magyarországon: A tudás és az érzelmek ellentmondásai. A jelen tanulmány a tűzifa termelésével és felhasználásával kapcsolatos attitűdöket vizsgálja. Telefonos felmérést végeztünk, strukturált kérdőív segítségével, amelyből 603 felhasználható válasz érkezett. Az elemzés kimutatta, hogy a tűzifát használók két alapvető környezetvédelmi koncepciót támogatnak: azt, hogy a tűzifa egészséges fákról való kitermelése elfogadható, és azt, hogy a tűzifa elvileg szén-dioxid-semleges. A válaszadók jelentős része azonban aggodalmát fejezte ki amiatt is, hogy a tűzifa felhasználása potenciálisan hozzájárulhat az erdők degradációjához és fokozhatja az éghajlatváltozást. Ezen attitűdök további feltárása érdekében a válaszadókat három különböző csoportba soroltuk. A statisztikai elemzés jelentős különbségeket tárt fel e csoportok között az iskolai végzettség és az életszínvonal tekintetében. Az összetett környezeti kérdésekkel kapcsolatos attitűdöket túlnyomórészt az általános környezeti aggodalmakat tükröző érzelmek befolyásolják, ami a lakosság korlátozott tudásbázisának köszönhető, ami akadályozza őket a tényszerű értékelésben.

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1 INTRODUCTION

Woody biomass plays a significant role among renewable energy sources in Europe, which the recent energy crisis has underscored (Carnia et al., 2020; Kożuch et al., 2023). Firewood is a vital heating source in Hungary, used by 1,398,278 households, representing a 31% share of all households. It is the second most common home heating fuel after natural gas (Central Statistical Office, 2022).

This study focuses on three aspects of firewood use. First, as a traditional energy source, it is produced in large quantities. Consequently, it contributes to the economic output of forestry significantly and plays a crucial role in the energy supply. Second, wood harvesting from forests induces concerns that production can lead to environmental disturbances or even permanent degradation. Third, wood combustion is often associated with air pollution even though firewood is renewable and its carbon cycle is almost completely closed. *Table 1* summarizes the above-listed aspects.

Table 1. Examined aspects of firewood use

	Production	Consumption
Contribution to the economy	Added value to the regional economy	Energy security improvement through diversification
Environmental impacts	Forest disturbance	Air pollution
Regulatory effects	Circular carbon-flow Competition to other wood products serving as carbon pools	

Forests are vital natural assets, and their utilization increases the added value in the regional economy. Exploiting this economic potential is crucial in rural areas where economic activity is lower than in urban areas (Huttunen, 2012). The availability of other energy sources, such as natural gas, coal, and electricity, influences firewood demand and prices (Trømborg et al., 2008). Beyond that, regional and national energy security heavily depends on a diversified energy mix (Ladanai and Vinterbäck, 2009; Mydlarz et al., 2024). The energy crisis caused by the Russian-Ukrainian war revealed the importance of adaptability (Balmaceda et al., 2024). The crisis caused the prices of various energy sources, including gas, crude oil, and coal, to surge (Zaid and Farooque Khan, 2023), instigating a shift in household heating preferences in Hungary (Tóth et al., 2024). Rising natural gas prices may increase reliance on firewood because the choice between the two most common heating options primarily depends on relative costs (Csuvár, 2019).

Rising firewood prices increase competition in paper, wood, and fiberboard markets, which is a significant economic consideration (Nepal et al., 2019) because industrial utilization generates larger added value. Such utilization also provides opportunities for longer-duration carbon content storage, thereby creating or maintaining a carbon pool (Király et al., 2019).

An advantage of firewood is that it contains carbon sequestered from the atmosphere, and its continuous production by sustainable forest management maintains a closed carbon cycle. Other alternatives, especially fossil fuels, entail permanent carbon dioxide emissions (Matthews and Robertson, 2001; Pierobon et al., 2015; Jayakrishnan et al., 2022). Under a constant environment, all energy and matter circulating between the forest and its environment through its natural processes are in balance in the long run. The carbon cycle is no exception. A very low rate of carbon accumulation is observable in the soil. Firewood production does not disturb this cycle. On the contrary, it allows us to access the stored energy that the decomposition of organic matter would have released, all without benefiting humans.

Although the energy flow of forests can serve human interests, forestry activities disturb the natural process regardless of their intensity (Bouget et al., 2012). Firewood production necessarily decreases the amount of deadwood (Bölöni et al., 2017), which inevitably affects the ecosystem. Forestry practices of lower technical standards can have more significant consequences, such as degradation of tree species composition and vertical structure, micro-habitat loss, and soil damage. In extreme cases, the whole ecosystem can be damaged when forests are converted into tree plantations and their maintenance requires active management.

The most significant environmental effect of firewood use is the release of smoke (Lipfert and Lee, 1985; Press-Kristensen and Tolotto, 2021). Wood burning can cause indoor and outdoor air pollution, which poses serious health risks, depending on the technology used (WHO 2015). According to a report by the European Environment Agency (EEA), 96% of the urban population in the EU is exposed to PM2.5 concentrations that are harmful to health (Targa et al., 2024). The pollution may be severe if heating devices are unequipped with filters and/or the combustion is of low efficiency. The latter also depends on the moisture content of the wood (Price-Allison, 2019).

The above contradictions concerning the benefits of firewood production cannot be fully resolved. Research on the shaping of environmental attitudes and behavior by personality traits, emotional intelligence, knowledge, and social context, among other factors, has highlighted knowledge as the most effective predictor. Individuals with a comprehensive and profound understanding of environmental issues are more likely to demonstrate environmentally conscious behaviors. (Hadler et al., 2022; Ienna et al., 2022) Other studies claim that although knowledge has no significant direct effects on pro-environmental behaviors, it is a key factor that creates a starting point in a chain of causation leading to positive environmental attitudes (Liu et al., 2020).

Some of the above issues are covered by the elementary and secondary education curriculum, others are the focus of public discourse and are well articulated by the media, while others remain within professional circles. Therefore, different societal groups possess varying levels of knowledge. Coupled with dissimilar levels of susceptibility and interest, this results in a wide range of attitudes towards these issues. This study aims to reveal how firewood users, who are expected to understand the direct benefits of wood utilization, think about relevant environmental issues and how they fill knowledge gaps with emotionally based beliefs. We extend this analysis by describing the environmentally friendly lifestyle choices of firewood users.

2 MATERIALS AND METHODS

2.1 The field of study

A questionnaire survey was conducted to assess the attitudes of firewood users in settlements outside the capital and county towns of Hungary. *Figure 1* shows the number of samples by county. Residents of the capital and the county towns were excluded from the survey. According to the 2022 census of the Central Statistical Office—only 2 % and 9 % of the residences using firewood are located there, respectively. Wood combustion is, therefore, more common in rural areas in Hungary, with 55 % of homes using firewood in villages and 34 % in small towns (Central Statistical Office, 2022).

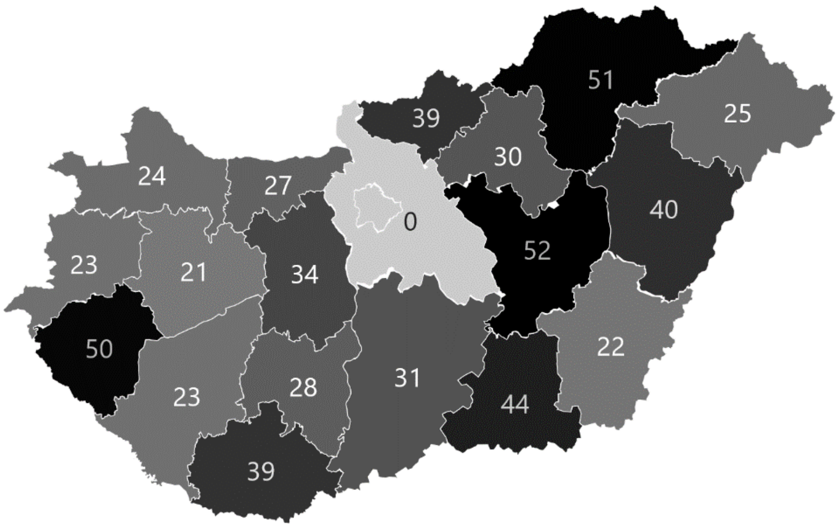


Figure 1. Sample distribution over the counties of Hungary

2.2 The survey

The questionnaire survey was conducted by M.A.S.T. Market and Public Opinion Research Company employing the C.A.T.I. (Computer Aided/Assisted Telephone Interview) methodology. The survey sample comprised adults with Hungarian citizenship residing in Hungary who have at least a partial reliance on firewood for their household energy needs. The survey yielded 603 usable responses, but systematic answers were excluded in some questions. It is vital to note that some of the questions in the questionnaire referred to the household as a whole and activities that are not necessarily performed by the respondent but by someone else in the household. Further questions, such as attitude questions, referred to personal beliefs and thoughts. While national statistics on households exist, no data on the demographics within households that use firewood is available. Thus, the representativeness of attitude questions cannot be assessed.

2.3 Data protection

Participation in the survey was voluntary, and respondents got no reward of any kind. Responses were recorded anonymously by the market research company; therefore, the authors did not need to handle personal information.

2.4 The questionnaire

The questionnaire consisted of 25 questions regarding firewood use habits covering the purpose of use, household energy infrastructure, procurement, handling, storage, and attitudes toward broader sustainability and environmental aspects of firewood use. Respondents can be characterized through nine demographic questions, including age, gender, education, type of residence, household size, and income. All questions were direct, closed-ended questions seeking numerical answers, choosing from the predefined options, or evaluating the question on a Likert scale. For some questions, optional answers included ‘other,’ and respondents could specify what ‘other’ meant in their cases.

The present study examines the survey results on attitudes and habits of firewood users regarding the environmental aspects of firewood use. Questions about attitudes were formulated in a broader sense so that they refer more to feelings than knowledge.

2.5 Methods used in the analysis

Responses were evaluated after excluding 'don't know' and 'no answer' results. Schematic answers were also excluded in Likert-scale questions. Consequently, the sample size varies from question to question and is indicated in each case.

Demographic differences between attitude groups of firewood users were tested with the Kruskal-Wallis test.

3 RESULTS

3.1 Demographic description of the sample

The respondents were mostly (73 %) above 51 years of age, while the younger generation, between 18 and 30 years, represented only 7 % of the sample. A slightly higher proportion of women than men participated in the survey (58 % vs 42 %). The majority (67 %) of respondents live in villages, and 33 % live in towns. In terms of education, the majority (67 %) of respondents cited secondary-level education, including apprenticeships and graduation, while those with higher and elementary education totaled 14 % and 18 %, respectively.

Table 2. Demographic data of the respondents

Age:				
18–30 years: 7 %	31–50 years: 19 %	51–65 years: 33 %	Over 65 years 40 %	No answer: 1 %
Sex/Gender:				
Female: 58 %		Male: 42 %		
Location of residence:				
Town: 33 %		Municipality: 67 %		
Highest completed level of education:				
Elementary: 18 %	Apprenticeship: 31 %	Graduated: 36 %	Higher education: 14 %	No answer: 1 %
Headcount of respondents' households:				
1 person 23 %	2 persons: 31 %	3 persons: 16 %	4 people 20 %	5+ persons: 10 %
Percentage of respondents with at least one child in the household:				
Yes: 38%		No: 62%		
The financial situation of respondents:				
Paycheck to paycheck: 25 %	Monthly expenses can be covered if no major expenditures occur: 48 %	Savings can be made over monthly expenses: 19 %	No answer: 7 %	

The size of the households represented in the survey showed an even distribution: 23 % were single-person households, 31 % were two-person households, while three, four, and five and more-person households were 16 %, 20 %, and 10 %, respectively. Households with non-earning children accounted for 38 %. Households that could only barely cover their monthly expenses (paycheck-to-paycheck) totaled 25 %. Households that could cover monthly expenses provided there were no unexpected large expenditures amounted to 48 %. Only 19 % indicated that their incomes allow them to save money. *Table 2* summarizes the demographic characteristics of the sample.

3.1. Attitude toward environmental aspects of firewood use

Our approach in this study treats the attitude toward firewood use as a mixture of knowledge and feelings with more emphasis on the latter. Knowledge covers facts and processes that together provide a basis for forming an opinion. The certainty and depth of knowledge of a non-professional do not allow for a clear and objective comprehension of the subject matter. Thus, panel arguments and impressions from public discussions can considerably influence opinions. Over time, these opinions can settle into attitudes.

The questionnaire included four statements regarding the environmental aspects of firewood production and use. The respondents were asked to indicate their level of agreement or disagreement with these statements on a 5-point scale. The statements were presented in a random order. Some were positively formulated, while others were negatively formulated.

One statement specifically targeted whether tree harvesting is acceptable if done sustainably (S1: 'A healthy tree can be harvested for firewood in the frame of sustainable forestry that entails replanting.') S1 eliminates the possibility that tree felling is rejected because it could potentially lead to deforestation and reinforces this by specifically mentioning replanting for those who are unfamiliar with the term 'sustainability.'

Another specific statement referred to the carbon-neutral nature of firewood. (S2: 'Firewood is a carbon neutral (environmentally friendly) energy source since the trees that have been cut get replanted by the foresters.') Carbon neutrality is a complex concept that cannot be evaluated without a basic understanding of underlying processes and their interrelations. Therefore, the questionnaire included a summary of the essence of carbon neutrality to avoid responses based on misinformation or misconceptions.

A more general statement is required to assess whether the use of firewood will harm forests (S3: 'The use of firewood for heating poses a significant threat to the forests of Hungary and their ecosystem'). This statement covers at least two mechanisms that potentially influence the state of forests. First, firewood production can directly degrade forests and forest ecosystems. This aspect is closely related to S1, which focuses more on acceptance, while S3 is asking about consequences. Consequences could be evaluated separately to the wood production potential and the natural state of the ecosystem. A detailed analysis would also separate the effects on natural forests and plantations. The second line of arguments covers the environmental effect of firewood use, most importantly air pollution, and its effect on forests. This complex statement could have been separated by these mechanisms, but then we would have received answers about the knowledge of the respondents and less about their attitudes.

The fourth statement investigated the effect of firewood use on climate change (S4: 'The use of firewood for heating significantly increases climate change.'). Similarly to S3, firewood use may have an impact on disturbing the carbon cycle on the harvest side and through air pollution. In the latter case, fumes from firewood combustion can be considered carbon emissions. Furthermore, air pollution, as a negative impact on the environment, can be falsely associated with climate change.

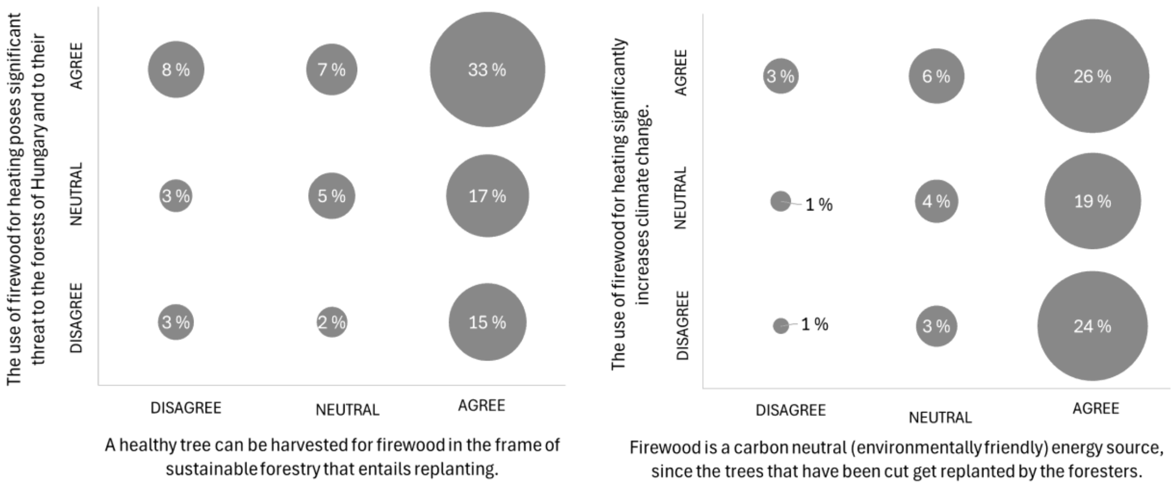
The first two statements (S1 and S2) attempt to narrow down the subject and reduce the possible role of misinterpretation of key terms. The latter two (S3 and S4) address complex concepts that are more likely judged by feelings and impressions rather than reason. Furthermore, there is a strong relationship between S1 and S3 as well as between S2 and S4, as S1 and S2 address core elements of the complex mechanisms behind S2 and S4.

Table 3. Responses to statements regarding the environmental aspects of firewood use (n=586)

Statements	Strongly agree 5	Rather agree 4	Agree/ disagree 3	Rather disagree 2	Strongly disagree 1	avg.	I do not know	No answer
S1: A healthy tree can be harvested for firewood in the frame of sustainable forestry that entails replanting.	34 %	33 %	15 %	9 %	6 %	3.7	2 %	0 %
S3: The use of firewood for heating poses a significant threat to the forests of Hungary and their ecosystem.	22 %	27 %	26 %	14 %	7 %	3.3	4 %	0 %
S2: Firewood is a carbon-neutral (environmentally friendly) energy source since the trees that have been cut get replanted by the foresters.	47 %	27 %	15 %	4 %	0 %	3.9	7 %	1 %
S4: The use of firewood for heating significantly increases climate change.	12 %	26 %	2 %	18 %	12 %	2.8	7 %	1 %

Table 3 summarizes the responses to the above-described statements. 67 % of respondents agree that even a healthy tree can be cut for firewood (S1), while 15 % reject the idea. There is also a clear majority (74 %) that agree on the carbon-neutral nature of firewood (S2). Only 4 % disagree with this statement.

Despite the divergent opinions regarding S1, 49 % of respondents believe that forestry is threatened by firewood production. Only 21 % deny this assertion. A similar trend is evident in the case of S4, where 38% of respondents consider firewood heating to be a significant contributor to climate change, while 30 % hold a contrary view.



(a) (b)

Figure 2. Contingency tables of environmental aspects of firewood production and use (a) Pair-wise adjudication of S1 and S3 (b) Pair-wise adjudication of S2 and S4

As *Figure 2* illustrates, 33 % of respondents concur with the view that harvesting healthy trees for firewood is a threat to forests, while 16 % disagree, asserting that firewood use does not pose a threat to forests. The results are very similar in statements about firewood as a carbon-neutral energy source and that its use increases climate change, as these statements are supported by 26 % of the respondents. 24 % of the respondents think that firewood is a carbon-neutral energy source and that its use does not increase climate change.

3.2 Characterization of respondents according to their general attitude toward firewood

Survey participants who gave 1–5 responses to all four statements (S1-S4) were classified into three groups. Participants who chose 'I do not know' or 'No answer' to any of the four statements were excluded from the classification. Those responding 'Agree/disagree' to all four statements were also excluded. Altogether, 477 respondents remained in the sample.

The first group, 'Firewood supporters,' consists of people who see firewood positively or neutrally in all four questions. They responded 5-3 to S1-S2 and 3-1 to S3-S4.

The opposite group is called the 'Firewood critics,' formed from those who expressed negative opinions consistently by responding 3-1 to S1-S2 and 5-3 to S3-S4.

The rest of the respondents are classified as 'Miscellaneous.' Here belong those who have at least one positive and at least one negative opinion on the environmental effects of firewood production and use.

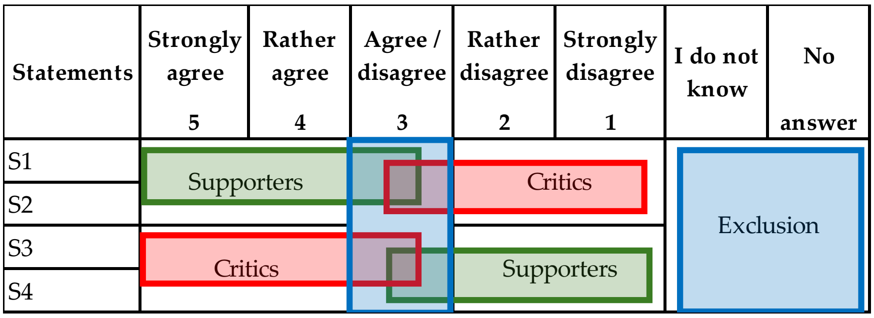


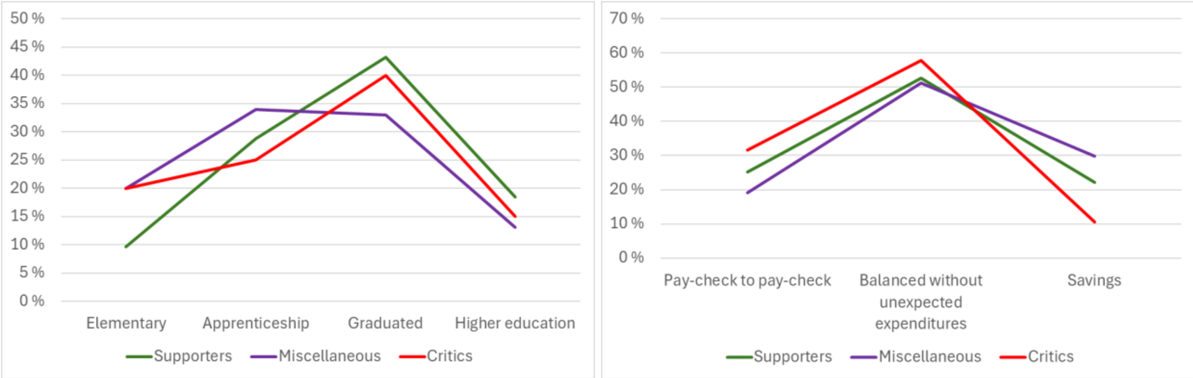
Figure 3. Criteria of classification of the respondents

Figure 3 summarizes the classification criteria. The size of the above categories was:

- Firewood supporters: 148
- Miscellaneous: 309
- Firewood critics: 20

We examined whether there were differences in demographic characteristics between respondents of the three different groups. For this purpose, a nonparametric test, the Kruskal-Wallis test, was used because not all dependent variables have a normal distribution.

As *Figure 4* shows, education and living standards were found to be significantly different between the three groups. Education among Supporters is higher than among Miscellaneous and Critics. A similar, but not entirely the same, phenomenon can be observed in the case of living standard, as Supporters have a higher living standard than Critics, but Miscellaneous have even higher.



(a) (b)

Dependent variable	p
Age	0.659 (N: 472)
Sex	0.6962 (N: 477)
Type of residence	0.8293 (N: 477)
Education	**0.0039 (N: 472)**
Household size	0.4938 (N: 476)
Living standard	**0.0391 (N: 439)**

(c)

Figure 4. Demographic differences between attitude groups. (a) Distribution of respondents over education categories (b) Distribution of respondents over living standard categories (c) Results of the Kruskal-Wallis test (N values vary according to the demographic data availability).

3.3 Environmental awareness of respondents

The survey included a series of statements about lifestyle choices and habits that either symbolically or meaningfully contribute to environmental protection. Respondents were asked to rate these statements on a 5-point scale according to how typical each was for them. *Figure 5* details the results.

Selective waste collection is the most supported item on the list (93 % combined agreement), closely followed by eating local food (90 %) and well behind avoiding plastic packaging (66 %). Although the former is indeed common in Hungary, it is unclear how local 'food source' was understood and what role local food plays in the diet of the supporters. There may have been some confusion between local grocery stores and local food sources.

Another group of statements relates to alternatives to car use. Walking and cycling instead of driving are supported by a slight majority (55 % and 52 % respectively), while public transport is only supported by 39 %. Given that the survey was conducted in rural areas and in small towns, these answers make perfect sense, as short distances allow walking and cycling, while public transport is only available for commuting to nearby cities, which affects only a part of the population.

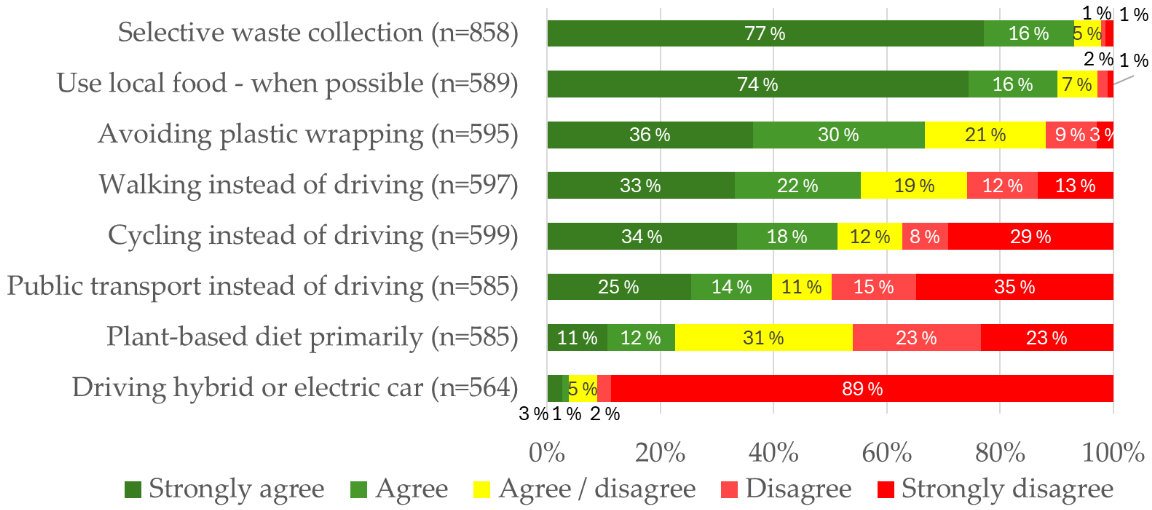


Figure 5. Habits and lifestyle choices with environmental considerations

The least supported statements are a plant-based diet (23 %) and driving an electric car (4 %). The latter has an overwhelming rejection (89 % strongly disagree), which is probably a clear reflection of the low share of electric and hybrid cars in rural areas. Although it is coupled with the highest share of neutral answers (31 %), the low support for a plant-based diet is surprising in comparison to the strong support for local food sourcing. The reason for this balanced distribution of responses may be that, apart from vegetarian and vegan diets, it is difficult to objectively assess how much of a diet is plant-based.

4 DISCUSSION

4.1 Firewood users

Firewood is produced in 1 m or 2 m lengths and less than 50–60 cm in diameter. The moisture content depends on the season and species. Firewood processing includes cutting and splitting, which are rather noisy and dirty and require space. Wood should be dried for at least a whole summer before combustion. All these requirements and circumstances determine that firewood is used more in less urbanized regions. Ready-to-use firewood can be a solution in cities to the above inconvenience, but only if it is a supplementary energy source because of the lack of storage space that can cover all energy needs for heating, hot water, and cooking. For this reason, firewood use in large cities has been phased out since the advent of natural gas. Currently, 92% of dwellings in the capital and county cities are heated with gas or electric appliances in individual or district heating systems (Central Statistical Office, 2022). In heavily populated areas, air pollution is another argument against all solid energy sources, including wood.

Based on the reasoning above, the study targeted firewood users living in villages and small towns, and the sample evenly covers all parts of the country. The survey's representativity cannot be tested because of the lack of demographic data for the whole population. Nevertheless, important insights can be gained about the attitudes toward firewood and its environmental impacts.

One of the results of this survey is that the dominant user group of firewood lives in households of 1 or 2 people, typically without children.

According to official statistics and related studies (Bajomi et al., 2022; Kármán-Tamus and Pálvölgyi, 2022), firewood use in Hungary is most common among the poorer, rural population.

The social, environmental, and economic sustainability of life in rural small settlements depends on many factors where income status plays a significant role (Szlávik – Csete, 2004). Such information is sensitive and private. Therefore, the questionnaire included only general questions regarding the living standard. The results show that the majority of firewood users are living in a balanced financial situation.

4.2 Environmental attitude

This survey was an initial attempt to reveal how attitudes toward firewood are constructed from elements of knowledge and emotions. Although firewood users are not directly involved in firewood production, their insights about firewood use may allow for more balanced views than what we can expect from outsiders.

Answering attitudinal surveys is challenging for the respondents because they are asked to make judgments about complex issues in a relatively short time. In such situations, respondents rely on their pre-existing knowledge or their emotions, making it difficult to assess the responses and uncover underlying motives and causations. However, public attitudes can have a strong influence on various policies. Therefore, they will shape future forests and forestry.

The most accepted (74 %) claim by far was that firewood is carbon neutral. This seems to be a more widely embedded view in society. Harvesting a healthy tree for firewood is acceptable to the majority of respondents (67 %), provided a seedling or sapling is planted to replace it. These results represent situations where a simple environmental concept worded reassuringly and explained well helps gain acceptance.

At the same time, a large proportion (49 %) of the respondents consider firewood use as a serious threat to the forests and their wildlife. Similarly, a smaller but significant proportion (38 %) believes that firewood use increases climate change. Although responses to the effects of firewood on climate change are evenly distributed, they contrast with the answers on carbon neutrality. These results represent situations when a more complex environmental issue, presented without reassuring or explanatory elements, allows more room for emotions and preconceptions.

For the contradictions between the views on a complex concept and its principle, at least four possible reasons can be identified:

- Respondents express a well-grounded opinion and agree with the basic concept, but due to other factors, the related broader concept is not valid, and they disagree with it.
- The wording of the core concepts is more assuring and tries to avoid misinterpretation, while the complex concept is presented without any additional information that could help the interpretation.
- The respondents have little knowledge about the complex concept. They might not realize the relationship between the concept and its fundamental principle, and their answers are more based on feelings and impressions.
- The respondents tend to agree on whatever question they are asked in a questionnaire.

Sustainable forest management is regulated by law in Hungary, and the forest area is increasing. However, the image of Hungarian forestry that respondents hold may be starker than reality. In theory, they agree with the idea of harvesting forests for firewood, but they do not perceive the necessary conditions for this, namely sustainable forest management. This is also linked to the acceptance of carbon neutrality, which is based on the continuous forest cycle and carbon sequestration. There could be a lack of confidence that what works in theory is implemented in practice, i.e., emitted carbon is sequestered. In a national-level representative opinion poll conducted a few years ago, the majority of Hungarians did indeed think that the forest area in Hungary was decreasing. In addition, many people believed that the condition of forests had even gotten worse (Lomniczi, 2017). The energy crisis caused by the Russian-Ukrainian war has led the Hungarian government to proclaim many measures related to firewood production, trade, and public supply. The government decree was heavily criticized by conservation NGOs and the media (Lett – Hegedűs, 2024). Many articles defending Hungarian forests and sustainable forest management against the firewood decree have reached the public through the mass media. The effects of these could be reflected in the results presented.

However, carbon neutrality does not necessarily mean climate neutrality, not even in the scientific literature (Sterman et al., 2022). Respondents may also have thought that burning firewood hurts the climate in the short term because carbon is released into the atmosphere and sequestrated only in the distant future.

The classification of the respondents showed that 31 % hold a positive opinion about the environmental impact of firewood use and expressed no negative responses. We call this group Firewood Supporters. Only 4 % of the respondents are on the opposite side, with no positive responses; hence, the name Firewood Critics. In between, with a 65 % share, is the largest group called Miscellaneous. This group offered mixed responses with at least one negative and one positive opinion.

Statistical analysis revealed that these groups differ significantly in terms of their level of education and standard of living. Firewood Supporters have the highest level of education, followed by the Firewood Critics and Miscellaneous group. This result may partly explain why the Miscellaneous group, the least educated group, gave contradictory responses.

The living standards of the groups under consideration also differ from one another, in descending order: Miscellaneous, Firewood Supporters, and Firewood Critics. Although the difference is proven by statistical probing, no evident link has been found to demonstrate how this influences the research results.

4.3 Environmentally conscious behaviors

Nationally representative surveys indicate that a significant proportion of the Hungarian population believes it is doing the right thing for the environment, even if it costs more money and time. Most agree that it is worth doing something for the environment, even if others do not (Schneider – Medgyesi, 2020). The population considers it vital to promote environmentally conscious lifestyles and conscious consumer behavior in society. They also consider it crucial to reduce the amount of waste generated and collect waste selectively (Borda et al., 2016). A positive trend can be observed in Hungarian society in the latter area between 1993 and 2019. However, fewer people are now willing to pay higher prices to protect the environment than in the past. Our survey of firewood users confirms the results of previous research. The majority of respondents avoid plastic packaging, collect waste selectively, and buy local food when they can. In this respect, therefore, Hungarian firewood users continue the attitudes of the rest of society. On other issues, the attitudes of our sample were already divided. On the other hand, transport issues may also be influenced by the characteristics of rural life, such as the varying quality of public transport or the number of electric charging stations. However, a plant-based diet would be a factor independent of place of residence, and the majority of our respondents do not pursue this. Incidentally, 39 % of Hungarians say they would reduce their meat consumption to reduce the negative impact of climate change. This is five percentage points below the global average (Ipsos, 2022). Although we did not ask the same question, 46 % of respondents in our survey are negative in this regard, while a further 30 % are more neutral.

If we examine attitudes toward matters other than heating, firewood users generally follow the environmentally friendly behavior of the Hungarian population as a whole. Of course, we must consider that respondents may try to present themselves in a positive light when asked about environmental issues, resulting in a slightly more favorable picture of respondents' pro-environmental behavior than the reality.

5 CONCLUSIONS

This research provided additional evidence that attitudes toward the environmental effects of firewood production and use are determined by factual knowledge but also emotions. The more complex the issue and the less stable and detailed the knowledge, the revealed attitude tends to reflect the general environmental concerns and tends to result in contradictory opinions.

While opinions may be contradictory, firewood users generally hold a more positive view of the sustainability of firewood compared to negative perceptions.

The present research study allowed only a few attitude-related questions in a wide-focused survey, which must be considered when assessing the results. Therefore, in-depth analysis is required to gain more precise information concerning knowledge and knowledge gaps, the influence of public discourses, impressions, and personal emotions that play significant roles in shaping attitudes.

These results highlight the differences between public opinion based on sound knowledge and knowledge with gaps. The public is often involved in decision-making processes and policy formulation to gather information and take account of a wide range of interests. However, the public also validates such processes and increases acceptance of the results. Participatory processes should place particular emphasis on communicating the facts, processes, and broader context under the proposed outcomes so that stakeholders and the public have easy access to them.

These findings suggest that environmental issues should be integrated into primary and secondary education to allow the broadest possible range of society to learn about the issues and gain the knowledge needed to assess them. Moreover, environmental education for children outside school and information for the adult population should be further developed.

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Contents and Abstracts of the Bulletin of Forest Science

Bulletin of Forest Science (Erdészettudományi Közlemények) is a journal supported by the Forest Research Institute of the Faculty of Forestry of the University of Sopron. The papers are in Hungarian, with English summaries. The recent issue (Vol. 14, 2024) contains the following papers. The full papers can be found and downloaded in *pdf* format from the journal's webpage (www.erdtudkoz.hu).

Vol. 14, Nr. 1, 2024

Abstract – The establishment of naturalisation attempts with the North American Eastern white pine (*Pinus strobus* L.) has a history of almost 60 years in Hungary. The ecological requirements of this species are balanced, humid climates and it is not suitable for establishing new afforestation under marginal site conditions. Eastern white pine stands established in the Trans-Tiszanian region, mainly near Debrecen, belong to yield classes IV and V based on the yield table of the Scotch pine (*Pinus sylvestris* L.). Their volume for a given age does not differ significantly from that of the Scotch pine stands. Eastern white pine stands mixed with northern red oak (*Quercus rubra* L.) and Scotch pine did not produce any surplus yield of practical importance. Even taking into account the negative effects of local climate change, the potential for the cultivation of Eastern white pine in the studied area is not promising.
https://dx.doi.org/10.17164/EK.2024.01

Abstract – As forest-based climate change mitigation gains greater importance within international climate policy, understanding the mechanisms influencing the carbon offsetting capacity of the sector becomes increasingly important. Our study evaluates the climate benefits of contrasting forest management strategies: one focuses on reducing harvest and expanding forest carbon stocks, while the other aims to increase harvest to enhance carbon uptake, wood product carbon pools, and substitution effects. We analyse the carbon balance of the Hungarian forest industry under three scenarios: the business as usual (BAU) scenario with no changes in current harvest and afforestation levels, the extensification scenario with reduced harvest and afforestation levels, and the intensification scenario involving increased afforestation, improved wood assortments, and gradually increasing timber extraction which is still meeting sustainability criteria. We introduce the Forest Industry Carbon Model (FICM), a novel carbon accounting tool encompassing various carbon pools including forest biomass, dead organic matter, soil, harvested wood products, and emissions avoided through

product and energy substitution. Our findings indicate that the intensification scenario performs the highest net removals and optimized product and energy substitution effects. By 2050, the net carbon balance of the forest industry will reach –8,447 kt CO_2 eq in the BAU scenario, –7,011 kt CO_2 eq in the extensification scenario and –22,135 kt CO_2 eq in the intensification scenario. Although substitution effects are not accounted for under the land-use, land-use change, and forestry (LULUCF) sector in Greenhouse Gas Inventories, emission reductions in the industry and energy sectors positively influence the national carbon balance. Our projections reveal that Hungary can meet the 2030 LULUCF greenhouse gas removal target set by EU legislation under the intensification scenario, necessitating significant innovation within the wood sector. In comparison, forest non-utilization proves to be a short-term solution, with its favourable effects diminishing by 2050 and leading to additional emissions as compared to the BAU scenario. This article is based on the original publication by Borovics et al. 2024 (Projection of the Carbon Balance of the Hungarian Forestry and Wood Industry Sector Using the Forest Industry Carbon Model).
https://dx.doi.org/10.17164/EK.2024.02

Attila FÁBIÁN, Ferenc LAKATOS, Veronika ELEKNÉ FODOR, Árpád ŐRSI, András NÁHLIK and András POLGÁR:

Applied sustanibility modell of the University of Sopron …33–46

Abstract – The University of Sopron has created the Sustainable University Model of the University of Sopron (SOE-FEM) based on its best practices, applying a systemic approach based on sustainability criteria. In the Institutional Sustainability Strategy, it defines its vision and SMART goals, for which it assigns an Implementation Program. Through university measures and work packages (WP), the model supports the implementation, operation and continuous development of the Sustainable University. The SOE-FEM is embodied in a pyramid model, with which we aim to create a university operating culture that treats sustainability as a priority and that can continue to spread in other sectors and in a wider social circle. Based on the Sustainability Strategy, the university announced the "Sound of Earth University of Sopron" Implementation Program (SOE-MP) under trademark protection. The implementation program of measures is in line with the UN Sustainable Development Goals (SDGs), and it provides a framework for the complex implementation and continuous development of the institutional sustainability culture. An essential element of the SOE-MP is the "University as a Living Lab Concept" roach.
https://dx.doi.org/10.17164/EK.2024.03

Gábor ILLÉS and Endre SCHIBERNA:

Assessing afforestation potential on the basis of ecological datasets …47–61

Abstract – Within the framework of the Károly Kaán national afforestation program, we examined the change in afforestation potential in our country. During the tests, we used two climate change scenarios, based on the RCP 4.5 and RCP 8.5 emission forecasts. We determined the approximate size of areas that could be afforested in the future in the case of low-quality arable land, grassland or pasture land, and good-quality but steep arable land. We also examined how this opportunity changes over time. Areas that can be afforested sustainably were considered to be those whose soil is forest soil and/or which have an additional water supply available for the stands, and whose estimated potential for timber production reaches at least the 4th yield class. The results showed that currently approx. 456,000 ha of land land may be suitable for afforestation may be among the low-quality arable land, but only 123,000 ha of this can be found on forest soils. Together with grassland and pasture areas, under similar conditions, this number can rise to 262,000 ha. However, as a

result of climate change, depending on the climate change scenarios, the proportion of areas suitable for afforestation decreases by at least 10 % every 30 years in the examined land use categories. In addition, the enforcement of nature conservation aspects results in a further area reduction.
https://dx.doi.org/10.17164/EK.2024.04

Éva KIRÁLY, Gábor KIS-KOVÁCS, Zoltán BÖRCSÖK, Zoltán KOCSIS, Péter KOTTEK, Tamás MERTL, Gábor NÉMETH, András POLGÁR and Attila BOROVICS:

Mitigating climate change through wood industry measures in Hungary …63–86

Abstract – Harvested wood products (HWPs) hold a significant amount of carbon, with long-lasting products and wooden buildings being some of the most effective methods for carbon storage. Extending the lifespan of wood products, along with proper waste management, recycling, and reuse, can further help meet climate goals. In our study, we projected the carbon storage, carbon dioxide, and methane emissions of the Hungarian HWP pool up to 2050 under 10 different scenarios to identify the combination of wood industry measures with the greatest impact on climate change mitigation. We utilized the country-specific HWP-RIAL model to forecast emissions related to the end-of-life and waste management of wood products. Our main finding is that without additional measures, the Hungarian HWP pool would turn from a carbon sink to a source of emissions by 2047. To ensure the Hungarian HWP pool remains a carbon sink, it is crucial to implement further climate mitigation strategies, including cascading product value chains and circular bioeconomy approaches. The most effective individual measures include increasing product half-life, boosting the recycling rate, and enhancing industrial wood production through increased assortments and harvesting. By combining these measures, an average annual climate change mitigation potential of up to 1.5 Mt CO_2 equivalents could be achieved during the 2022–2050 period. This article is based on the original publication by Király et al. 2024 (Climate change mitigation potentials of wood industry related measures in Hungary).
https://dx.doi.org/10.17164/EK.2024.05

Tamás KOLLÁR:

Forest yield function and table of sessile oak (*Quercus petraea*) stands by the FRI's long duration research network database …87–111

Abstract – Yield table of sessile oak by the Forest Research Institute's long duration research network was publicised in 1981by Albert Béky. Since then a great amount of data was accumulated from the University of Sopron – Forest Research Institute's (UOS – FRI) long duration forest yield and silvicultural research network by continuous recordings. From that database new yield functions and yield tables were made in favour of more accurate estimation of sessile oak yield. Altogether 1329 digitalised records from 243 parcels were processed, from that great differences were noticed compared to the previous tables. Besides making the traditional yield table, the methods of calculations were given in detail, from which a forest stand's individual growth trends can be calculated. The tables were made assuming a 100 % sessile oak mixture ratio, closure and density.
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Anikó JAGODICS and Ernő FÜHRER:

Investigations on leaf litter and humus layers of beech forests in Zala County (Hungary) in relation to weather conditions …115–130

Abstract – The amount of organic matter in leaf litter and humus layers, the changes in their carbon and nitrogen stocks over time, and their correlation with weather conditions were investigated in experimental plots of European beech (Fagus sylvatica) in Zala County, based on samples collected in 2006, 2010 and 2013. The mass of organic matter was the highest in the samples of 2006. The amount of humus decreased considerably by 2010 and then reduced further by 2013. Accordingly, the carbon and nitrogen stocks also decreased. The C/N ratio of humus showed a moderate increase over the years; however, the values indicated a favourable mull-type humus form every year. These changes in quantity and quality can be related to the weather from January to March between 2007 and 2010 which were milder and wetter than the long-term average. Based on the samples collected before and after the autumn litterfall in 2013, we concluded that a 27 % decrease in the amount of humus can occur even within two months. Compared to the long-term average, the higher average temperature and precipitation sum of October–November may have contributed to the decrease in organic matter as a result of the intensification of decomposition processes.
https://dx.doi.org/10.17164/EK.2024.07

Attila BENKE, Valter TOLDI, Tamás SÜLE and Katalin BERECZKI:

Effects of fertilization on nutrient accumulation in black locust (*Robinia pseudoacacia* L.) leaves: results of an experiment in Tápiószele …131–144

Abstract – The basis of plantation forestry under often marginal environmental conditions is the use of varieties that can utilize the limited ecological conditions. In our research, the nutrient utilization capacity of different black locust clones (OBE01, OBE34, OBE53, OBE69) was investigated based on the nutrient content of their foliage. In the experimental plantation, which was established in poor sandy soil, different nutrient supplementation treatments were applied. Element utilization was evaluated based on leaf nitrogen, phosphorus, potassium, iron, manganese, copper, zinc and nickel contents, while the effect of each treatment on leaf element content was analyzed by calculating modified z-scores. Generally, the pure chemical fertilizer treatment had a predominantly negative effect on the macro- and microelement uptake of black locust clones (13 significantly negative and five positive relationships), compared to the treatments including organic fertilizer, which showed a predominantly positive effect (12 significantly negative and 27 positive relationships). Among the clones, the element uptake of OBE53 showed the strongest relationship with fertilizer applications.
https://dx.doi.org/10.17164/EK.2024.08

Klára CSEKE, Attila BOROVICS, Anikó JAGODICS, Botond Boldizsár LADOS, László NAGY, Attila BENKE and Tamás KOLLÁR:

The effect of thinning on the genetic structure of beech stands – a genetic and growth assessment of three long-term beech forest thinning trials …145–163

Abstract – The study aimed to evaluate three long-term beech (*Fagus sylvatica* L.) forest thinning trials from the aspect of changes in forest yield and to explore putative changes in genetic diversity in the stands of Kőszeg, Tormafölde, and Visegrád. In the trials, we analyzed the effect of traditional and intensive thinning on two plots compared to a theoretically unmanaged control plot. Based on the tree yield data sets, we could trace abiotic damages,

and in some cases, unplanned thinnings, especially from the 2000s onwards. The thinning effect on tree yield can adequately be evaluated on the plots of Tormafölde and partly in Kőszeg. The comparative analysis of the genetic diversity of the differently managed plots did not prove that genetic diversity would decrease due to thinning. The plots with the traditional thinning have almost the same or even higher genetic diversity values as the control plot. In the trial in Kőszeg, the two treated plots show higher degree of genetic similarity, while in Tormafölde, the traditionally thinned and the control plots are genetically closer to each other. The plots of Visegrád were not interpretable from both the view of yield changes and genetic patterns. The genetic diversity at the regional level was the highest in the forest stand of Kőszeg and the lowest in Visegrád.
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András SZABÓ, Zoltán GRIBOVSZKI, Ján SZOLGAY, Péter KALICZ and Bence BOLLA:

Investigation of the relationship between groundwater and the root zone in the Püspökladány-Farkassziget study site during the period 2020–2023 …165–176

Abstract – Forest vegetation is particularly sensitive to rapid environmental changes. In the case of forest stands on the Great Hungarian Plain, such changes may include the decades-long groundwater level decrease and the increasing length of drought periods. We have investigated the relationship between the root system of the forest stand and the groundwater level over four years at our study site at Püsökladány-Farkassziget, which is particularly exposed to aforementioned negative impacts, using high temporal resolution groundwater level and meteorological data. Our results show that by the end of the 2021 growing season, the connection between groundwater and the root system was partially, and by the same period in 2022, it was completely lost. We did not observe any positive changes in 2023. If this situation persists in the long term, it raises questions about the sustainability of the forest stand under investigation.
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Bálint HORVÁTH, Melinda NAGY-KHELL, Máté FARKAS, Tamás Márton NÉMETH, Katalin BERECZKI, Bence BOLLA, Virág JECZÓ, Lászlóné KISS, Valter TOLDI, Tamás FONYÓ and Gábor ILLÉS:

Study on the stand structure, lying dead trees and site characteristics in the Remetekert forest reserve …177–193

Abstract – Long-term monitoring system in the Hungarian forest reserves has started in 2005 and almost 40 forests were surveyed up until the present days. The Remetekert forest reserve was investigated in 2022 for the first time; the study focused i.a. on site characteristics (e. g. soil composition) and stand structure, supplemented with the relief model and measurement of lying dead trees. Lessivated brown forest soil dominated in the forest which was suitable for the stand forming forest types: beech woodlands and sessile oak-hornbeam woodlands. Sessile oak was dominant tree species within the site however, beech and hornbeam also were abundant. Average living stock volume was 555.61 m^3/ha, stand density was 762 stem/ha. Upper and lower canopy layer were typical, characterised by 20 meters and 14 meters average height. The distribution of lying dead trees was unequal, their average quantity was 24.75 m^3/ha.
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Csaba Béla EÖTVÖS:

Why we should research canopy processes and what methods are available …195–212

Abstract – As a result of climate change, we are experiencing accelerating changes in the canopy, affecting the communities that live there. These communities make up half of the total terrestrial biodiversity. To help maintain the ecological balance, canopy research is important, and researchers began to focus on it in the 1980s, quickly adopting existing tools and developing new ones. Choosing the right one for our purposes can often be difficult from this wide range of tools. This synthetic work is intended to help in these situations while pointing out the methods that can be used to acquire practical knowledge that can be applied in forestry.
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