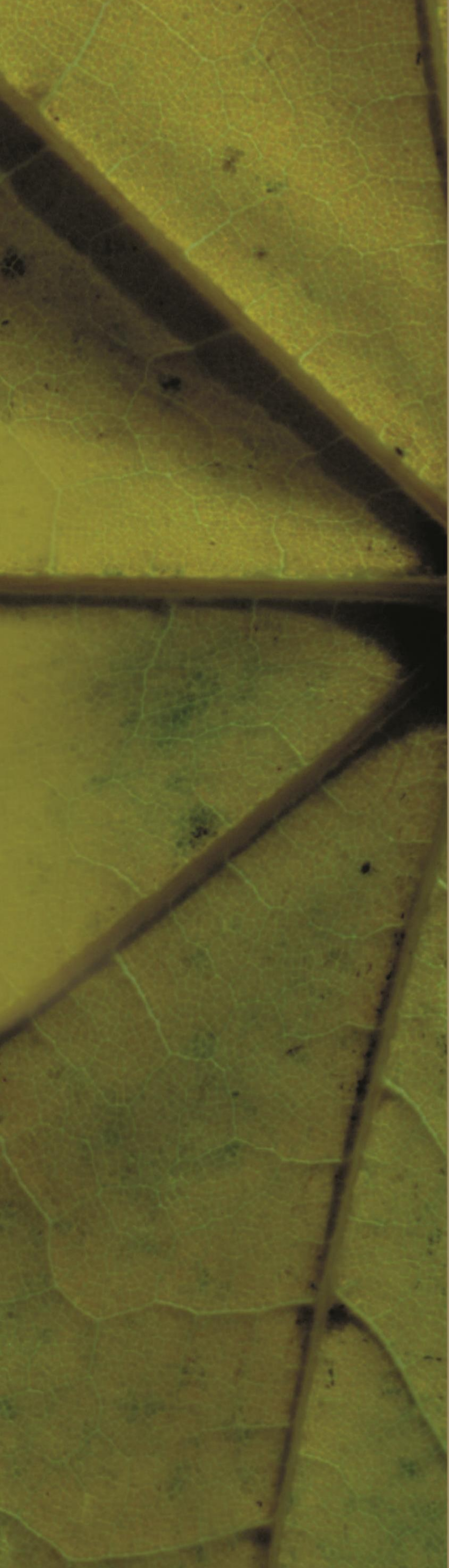

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Vol. 21, Nr. 1

Contents

ACTA SILVATICA ET LIGNARIA HUNGARICA

Vol. 21, Nr. 1

Tartalomjegyzék

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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.

TANULMÁNY INFÓ

Kulcsszavak:

Szakirányítás
Kivitelező vállalkozások
Szaktanácsadás
Kisvállalkozás
Vidékgazdaság

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.

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

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).

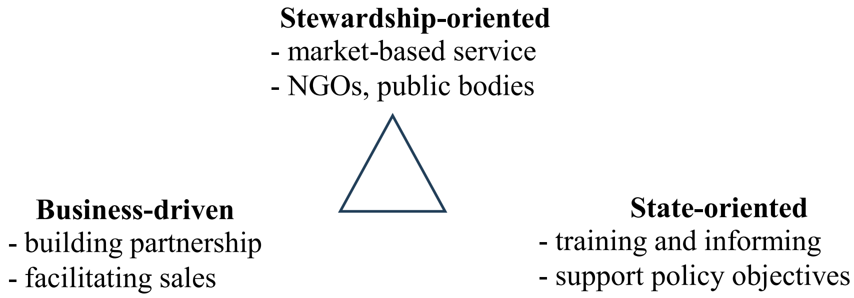

Figure 1. Characteristics of intellectual services providers by provider status

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.

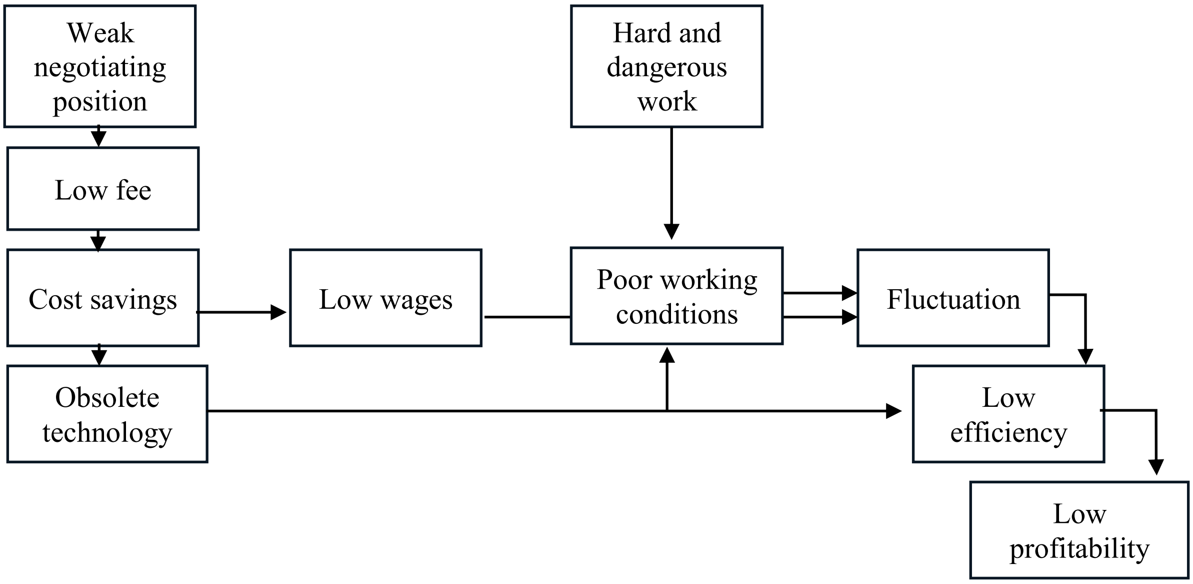

Figure 2. Consequences of low bargaining power of forestry contractors

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.

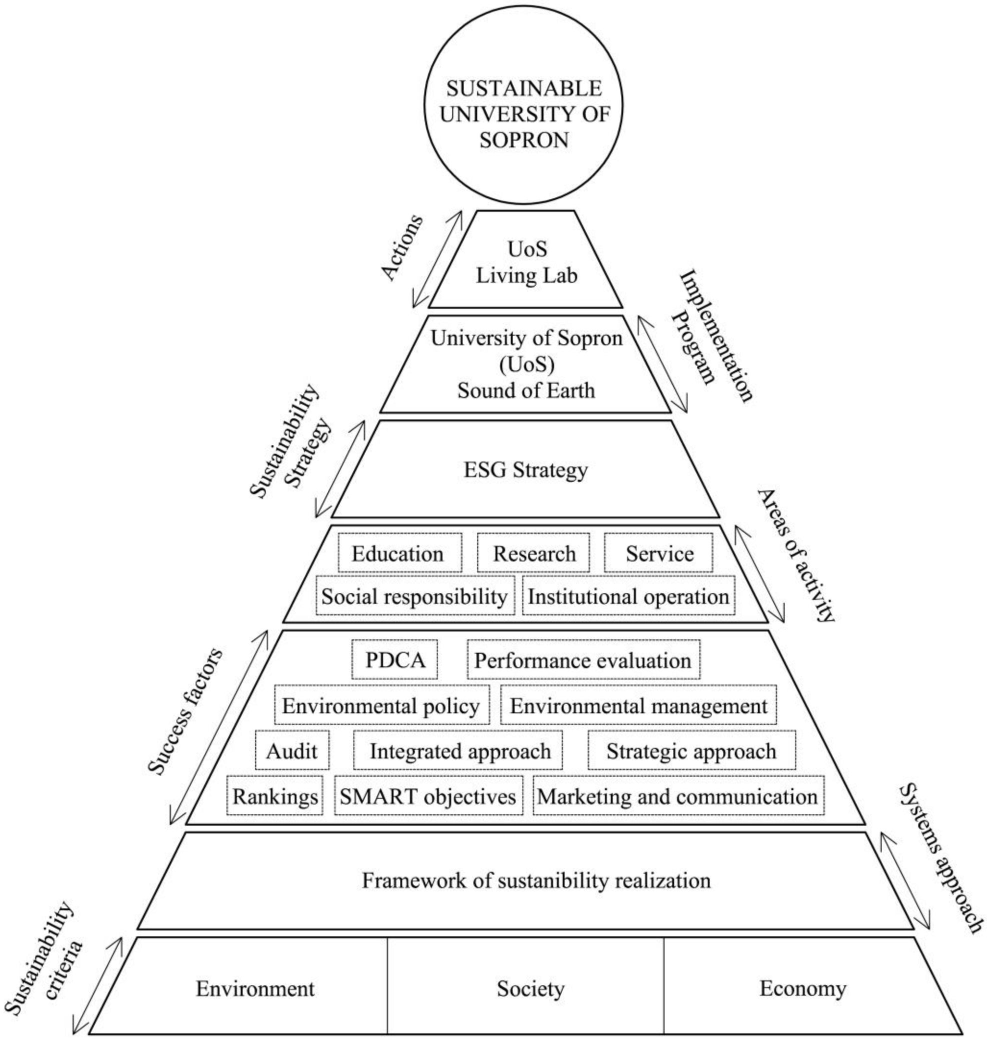

Figure 1. Pyramid model. The Sustainable University Model of the University of Sopron (SUM-UoS).

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 CO2 quota)
- optimizing the use of land and space (Abdelalim et al., 2015).

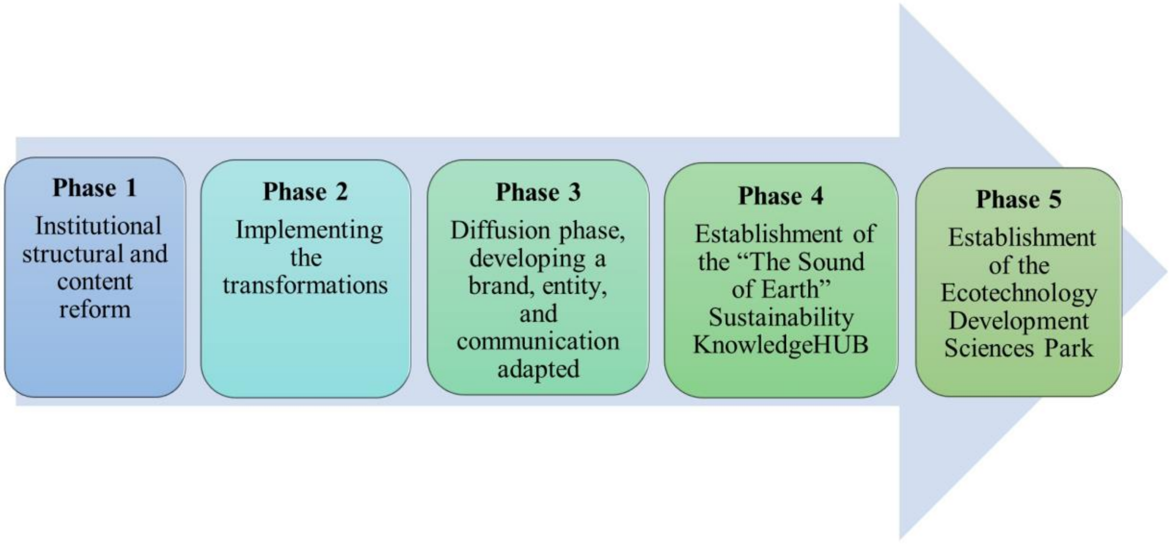

Figure 3. The Sustainable University Management Model of the University of Sopron

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

Kulcsszavak:
Erdei szimuláció
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 $80x50$).

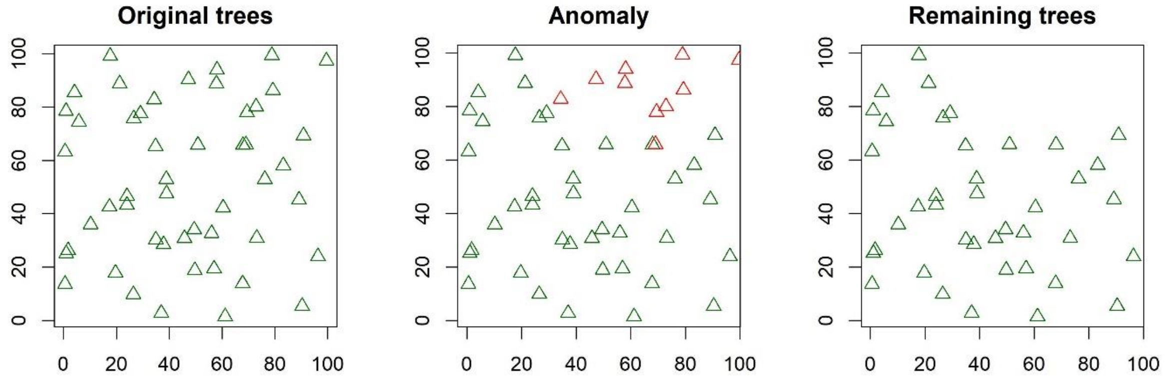

Figure 1. A potential anomaly affecting trees (m=50, l=10)

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 $e_j = \lambda a_j = na_j/a$. 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

$$H_0: \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 \quad (6)$$

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

$$H_0: \eta_i = \eta_j \ \forall i \neq j \quad (7)$$

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*).

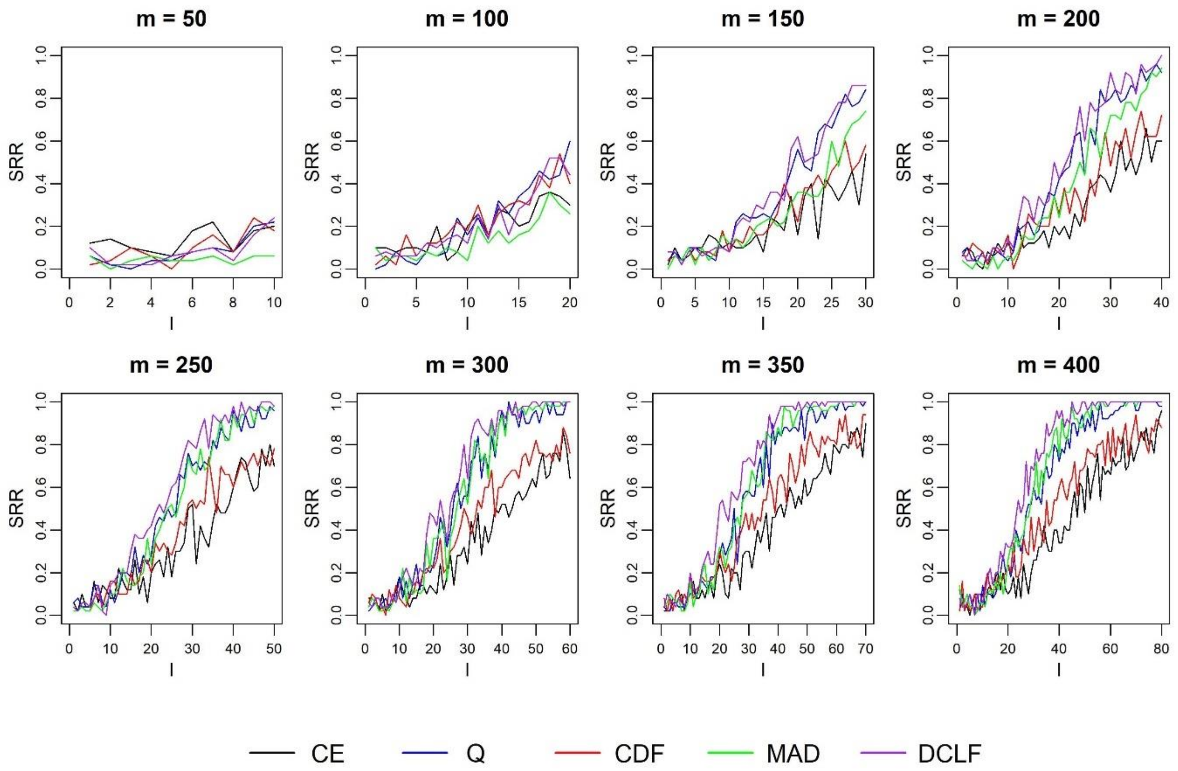

Figure 2. The proportion of significant results for each test under different m and l

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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Guide for Authors

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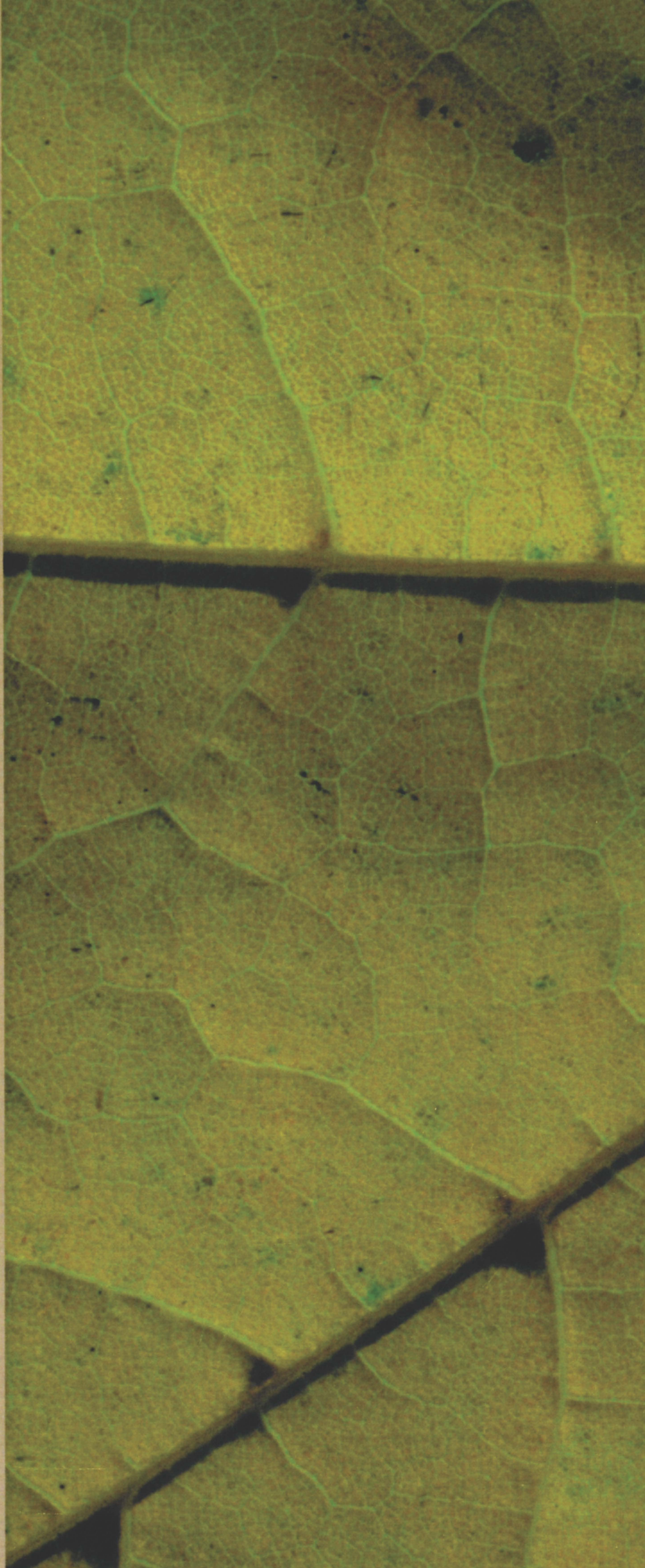

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