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Original Research

Valuation of Ecosystem Services for Implementing Innovative Clean Technology

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Abstract

Sustainable development of high nature value areas promotes the use of resources and services that rely on the unique assets of a particular ecosystem without undermining its integrity. Implementing innovative technologies, especially in the field of renewable energy sources, supports this process and helps to preserve environmentally valuable areas such as semi-natural grasslands. This study employs the ecosystem services valuation method to assess the environmental impacts of implementation of innovative IFBB technology in the Notec River Valley of western Poland as a part of a proposed implementation potential analysis framework. Six different categories of ecosystem services were analysed. Results show that implementing IFBB technology has a positive impact on the local ecosystem, generates additional value for potential investors, and thus could affect the perception of a renewable energy generation technology as being viable to implement.

Keywords: ecosystem services, renewable energy sources, innovative technology implementation, semi-natural grasslands, biomass

Introduction

Coupled with a dwindling fossil fuel supply, the rise in demand for energy has turned the attention of the research community toward sustainable and renewable energy sources. One of them is biomass, a resource expected to ensure an economically and environmentally balanced production of energy for sustainable economic growth [1]. One challenge in biomass energy generation lies in developing innovative technologies and securing its affordable supplies [2]. A viable source of such supplies may be the plant-mass produced on extensively harvested grasslands, many of which are protected in a variety of ways, including in the Natura 2000 network, with a view to preserving their environmental value. Biomass from such grasslands is poorly suited for use as animal feedstock. The use of grasslands falls outside of the scope of social land-use conflicts over areas with food production potential that are set aside for energy generation, as is increasingly the case with field crop biomass and especially corn silage utilized for biogas production [3-4].

In recent decades, the total area of environmentally valuable grasslands has declined steadily, mainly as a result of their abandonment due to drops in demand for grassland-derived feedstock caused originally by declines in farm animal numbers [5]. In effect, grasslands have diminished in value as an environmental, social, and economic asset. Over time, grassland landscapes have

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been losing their open-space advantage associated with low-growth vegetation, as the areas were increasingly invaded by expansive bush and even tree species [6-7]. Such adverse developments in grasslands has led to the disappearance of habitats that are vital for many animal species, including avifauna, which are highly dependent on grassland ecosystems.

To prevent further degradation of such habitats, it is crucial to restore their extensive use [8-12]. One remedy is to mow grasslands yearly late in the growing season to bring back plant and animal populations in a natural manner. This would leave mowed biomass available for energy generation. The requirement to harvest grasslands late in the season and remove the resulting biomass has been written into the terms of agri-environmental programs designed to conserve grassland communities, and specifically to ensure their biodiversity [13].
The financial support extended to high nature value (HNV) areas is intended to promote sustainable growth and provide incentives for using the resources and services that rely on their unique assets. Ecosystem services are a set of products (physical goods) and functions of an ecosystem that are used directly, support the potential for life, and improve its quality [14]. The ISO 13065:2015 standard defines ecosystem services as benefits provided by ecosystems that help improve the viability and quality of human life [15, 60].

Environmental diversity expands the range of ecosystem services that a given area can provide. The five identified categories of such services are basic, provisioning, regulating, cultural, and auxiliary [16]. Poskrobko [17] distinguishes between the bio-environmental and socio-economic views of ecosystem services. The bio-environmental approach defines such services as any environmental processes that create a human habitat that provides a quality foundation for societal development. Under the socio-economic approach, an ecosystem service is any significant function, such as air purification, waste degradation, and crop pollination.

In the case of semi-natural grasslands, particular emphasis is placed on the diversity of ecosystem services [18]. Fig. 1 presents semi-natural grassland ecosystem services and their impact on the quality of human life.

The majority of the above-mentioned ecosystem services that rely on semi-natural grasslands either cannot be substituted or are very costly to substitute with human activities. Thus, semi-natural grasslands are an essential part of the environment, making their preservation in the best possible condition a crucial endeavor. Human activities undertaken between 1990 and 2010 have left all known categories of the ecosystem services provided by grasslands severely degraded all across Europe [23].

Reversing such losses to the quality of environmentally valuable areas and in particular semi-natural grasslands calls for innovative solutions [24]. Much impact on the future of such areas is expected to come from private entities employing sophisticated technologies and environmental solutions to ensure the sustainable development of ecosystems. The main aims of organizations that follow this model include [25]:

– Preventing or mitigating impacts on the environment or any of its parts (e.g., ecosystem biodiversity).
– Using natural resources sustainably.
– Generating positive returns on activities.
– Ensuring a fair distribution of benefits derived from the use of biological resources.

Privately-held enterprises may thus become some of the key contributors to the protection of biodiversity in environmentally valuable areas. In keeping with the economic principles of sustainable growth, the main land use objective is to ensure sustainable socio-economic development. The resulting profits provide a measure of ultimate success [26].

However, a number of the properties of the biomass harvested in semi-natural grasslands, and especially

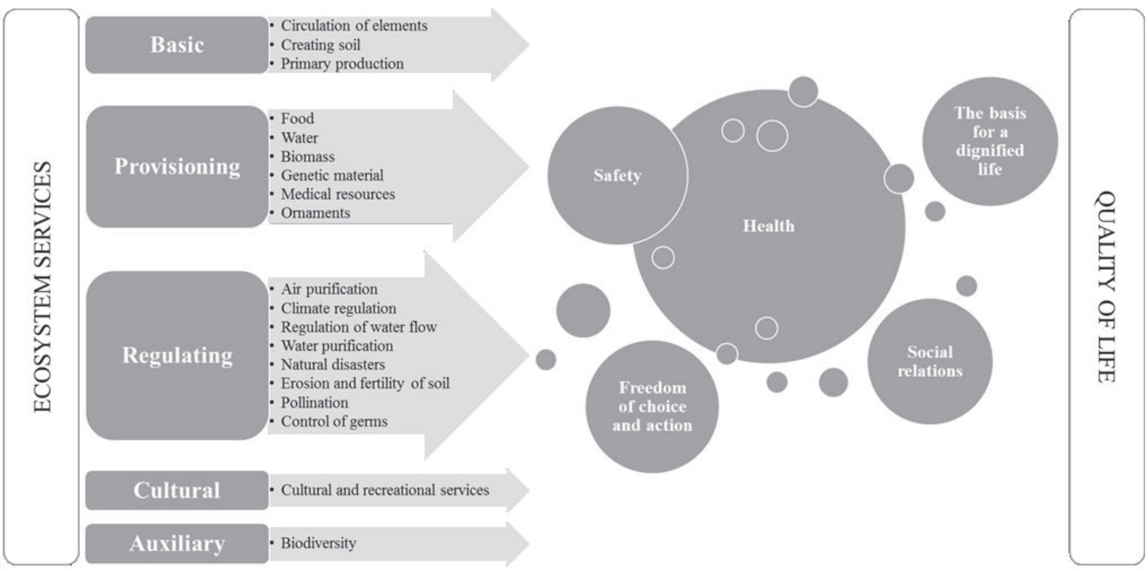

Fig. 1. Semi-natural grassland ecosystem services and quality of life. Source: Own work based on [19, 20-22]

those mowed late in the growing season, make their use for conventional energy production a daunting challenge. High content of lignin, cellulose, and minerals makes biomass a poor feedstock for either biogas production or direct burning. The biggest problem with grassland biomass is its high sulfur, chlorine, potassium, and magnesium content. Released in the burning process, these elements introduce harmful contaminants into the environment and shorten the usable life of many furnace components. Meanwhile, the profits derived from biogas are reduced by high cellulose and lignin content and low content of crude fat, crude protein, and nitrogen-free extract compounds [27].

Such challenges may be resolved by innovative integrated generation of solid fuel and biogas from biomass technology (IFBB). During hydro-thermal processing, biomass silage from grassland swards separates into a solid combustible fraction and a liquid biogas-producing fraction. The extraction of minerals and other water-soluble compounds that undergo hydrolysis as they leach from silage significantly increases the volumes of heat generated in press cake combustion. The resulting press fluid is a suitable substrate for biogas production [28]. The final outputs of the IFBB process are:

– Quality pellets or briquettes suitable for direct burning.
– Electricity and heat co-generated in a biogas plant.
– Nutrient-rich biogas digestate used as a fertilizer.

IFBB technology offers a way to generate energy from biomass harvested in extensively farmed natural and semi-natural grasslands and rush communities. It can also be used to produce energy from the biomass harvested in other grassland types, urban green areas, roadsides, and even from park and garden maintenance waste [29].

The case study for this paper is based on a pilot-scale test of the IFBB technology performed within the framework of the DanubEnergy project co-financed by the European Regional Development Fund (ERDF) of the European Union, Interreg CENTRAL EUROPE [30].

Data and Methods

The Prospective Investment Site

The research conducted within the framework of the DanubEnergy project demonstrated a huge resource-provisioning potential of environmentally valuable grasslands located in the Lower and Middle Noteć River Valley [31]. The area extends to the flood plains of the Noteć River from the town of Nakło nad Notecią in the east, all the way to the village of Santok in the west, covering a total area of approximately 78,000 ha. The valley serves as a vital natural corridor connecting the Odra and Vistula rivers and a bird sanctuary of European significance. One of its unique features are populations of rare and endangered animal and plant species. For that reason, more than a half of the Noteć River Valley has been incorporated into the Natura 2000 network. The part of the network located in the region comprises three special bird protection areas and two special habitat protection areas.

The Noteć River Valley is made up of more than 63,300 ha of permanent grasslands, 12,660 ha of which are incorporated into the agri-environmental support program – the main instrument for the protection of these habitats [32]. In 2015 the total value provided by the local biomass of grassland origin available in the region was estimated at PLN 26 million per annum. The majority of the Noteć River Valley is located within the Polish region of Wielkopolska.

The selected prospective investment site envisioned for the deployment of the innovative IFBB technology is located near the town of Drezdenko (52°49′04″N 15°48′03″E) in the Noteć River Valley (Fig. 2).

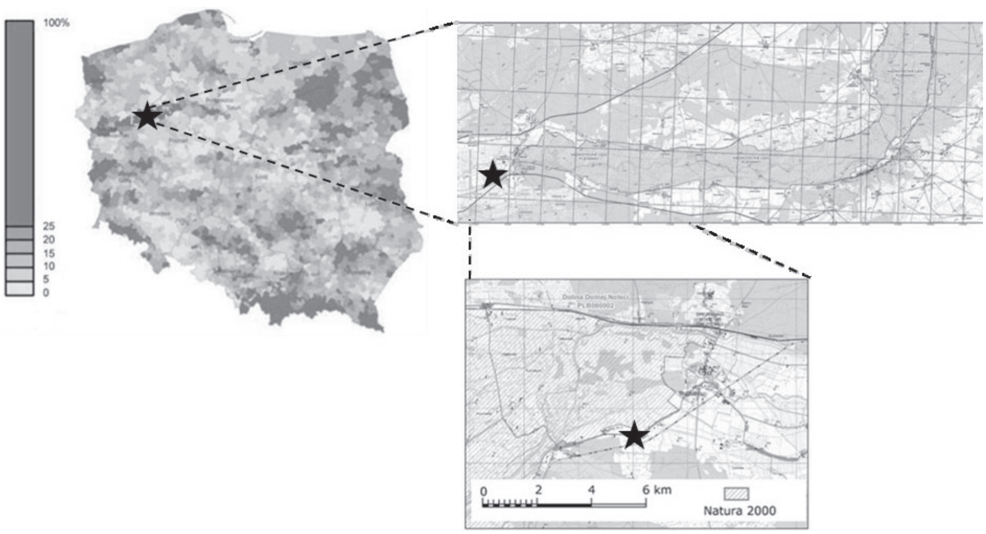

Fig. 2. Location of prospective investment site marked on a map showing permanent grasslands as a share of Poland's total arable land. Source: Own work based on [33]

Environmental Impact Assessment of the Project Using the Ecosystem Services Valuation Method

Quantitative ecosystem service assessments and valuations follow an innovative method that is increasingly popular as a critical factor in environmental protection decision-making and planning [34-39]. The approach calls for identifying areas of substitution between the value of quantitatively identified ecosystem services and the cost of their substitution with human activities. The ecosystem services concept demonstrates synthetic dependencies between the economic and environmental aspects of business activities [40]. The use of ecosystem services valuation as part of the assessment process may significantly affect the perception of enterprise efficiency [41].

The proposed approach to expressing ecosystem services in monetary terms relies on general presumptions, as no quantitative data is available on the specific supply and demand for individual services [42]. Without a doubt, the use of data derived from detailed empirical studies would help improve accuracy. One positive feature of the approach is that by converting the individual services available in a given ecosystem to monetary terms, common denominators are identified for assessing different environmental assets. Such unification is of particular importance in assessing environmental impacts from an enterprise's viewpoint [43]. The method allows one to track ecosystem changes that may affect enterprise standings. Adverse changes in the natural environment may affect the ability of enterprises to increase their worth and reduce their operating risks, especially for entities relying on renewable energy sources. The method additionally allows one to directly assess the environmental impact of specific decisions made by enterprises and may therefore enable them to make environmentally-sound choices. It also helps weigh various operating strategies and environmental protection options for specific areas [40].

Results

Ecosystem Services Valuation for the Purposes of Prospective Investment in the Noteć River Valley

Described below in detail is an ecosystem services valuation process for semi-natural grasslands in the Noteć River Valley, which are a resource base for the prospective investment envisioned to implement IFBB technology. The assessment area amounts to 962 ha of grasslands.

The categories of ecosystem services in semi-natural grasslands in the Noteć River Valley that have been considered are:

– Biomass production for energy generation purposes.
– Carbon capture and storage.
– Soil protection against erosion.
– Water retention.
– Use of biogenic components to prevent water contamination.
– Recreational use.

Biomass Production for Energy-Generation Purposes

Based on a review of economic factors and the data gathered by means of a regional exploration survey (as part of the implementation potential analysis framework – see below), an assessment was made of the biomass yield of semi-natural grasslands in the Noteć River Valley and its energy generation potential. The mean grassland biomass yield in the region in question stands at approximately 13 t FM ha^{-1} (5.2 t DM ha^{-1}). The price per ton of harvested biomass converted to silage is PLN 65 per t FM^{-1}. As is generally the case for biomass from semi-natural grasslands, despite its low efficiency, the resource is fit for use as either feed in extensive animal breeding or in energy generation, utilized in the form of combustion hay. Ecosystem services in the area in question were therefore valued at PLN 812,890.

The IFBB technology helps significantly increase the value of the harvested biomass by way of conversion to pellets with the desired heating value. The calculations were based on the wholesale price of such pellets of PLN 450 t^{-1}. The IFBB process helps produce 4.5 t of pellets per hectare of grassland given the yield of 13 t FM ha^{-1}. Thus, the IFBB technology increases the value of ecosystem services for biomass production to PLN 1,948,050 per annum.

Carbon Capture and Storage

Semi-natural grasslands have a large capacity for carbon capture and storage. This is associated with the net primary production (NPP) of a grassland ecosystem and its positive organic matter balance, in which carbon is accumulated and permanently stored in the topsoil [30]. The intensity of this process depends on grassland type and mowing regime. Grasslands in the Noteć River Valley are found mainly in flood plains and wetlands [44]. If extensive biomass harvesting is employed in keeping with the precepts of the agri-environmental program, carbon capture and storage capacities are estimated at 0.8 t of C per ha^{-1} per year [45]. Therefore, the area in question has the potential to capture and store approximately 770 t of carbon per year in grassland soil.

The economic value of carbon capture and storage is estimated on the basis of the marginal abatement cost (MAC). Based on the literature, the capture and storage of one ton of carbon is valued at EUR 95 [46]. Hence, the estimated ecosystem service of carbon capture and storage in the project area has a potential value of PLN 321,057 (given the foreign exchange rate of PLN 4.3913 to the EUR) [47].

Protecting Against Soil Erosion

The capacity to prevent soil erosion is assessed by comparing land uses [30]. In the case of semi-natural grasslands, one viable alternative is to use the area as arable land. However, if used to grow crops, the land will suffer from land erosion at the level of 3-40 t ha^{-1} per annum [48]. In contrast, semi-natural grasslands erode at the rate of 0.8 t ha^{-1} per annum [49], i.e., 2.2 t ha^{-1} below the lowest soil erosion rate achievable with field crops. This effect is made possible by the presence of turf in grassland ecosystems. This durable and tight plant cover effectively protects topsoil from being washed away by surface runoff and/or wind erosion. The semi-natural grasslands in question at the project site will therefore help retain 2,116 t of topsoil per annum.

Soil erosion costs arise on multiple fronts. They include not only such factors as the loss in an area's productivity, increased leaching of soil minerals, the deterioration of water resources in habitats, and the leaching of soil particles into water systems, which effectively reduces the available volumes of pure water while affecting water treatment and flood protection systems [50]. The value of protection against the adverse impacts of soil erosion are estimated at roughly EUR 116 per t^{1} [51]. Thus, the ecosystem service of protecting soil against erosion in the semi-natural grasslands of the Noteć River Valley can be valued at PLN 1,081,792.

Water Retention

Water retention measurements in a given ecosystem are based on the surface runoff coefficient [49]. Computed as a percentage of the rainfall converted to water runoff, the coefficient helps assess a given area's water retention capacity. The capacity of the grassland flood plains of the Noteć River Valley can be estimated at 180 m^3 ha^{-1} [52]. Given the average cost of building artificial retention tanks of EUR 16.5 per m^3 [52], the regulation function (of which water retention in valley grasslands is a form) is worth PLN 12,546,559. This makes it the most valuable ecosystem service component falling within the scope of the assessment, highlighting the critical role of grasslands in natural water storage with beneficial impact on neighboring ecosystems and additional flood protection benefits.

Using Biogenic Components to Prevent Water Contamination

Semi-natural grasslands play a key role in retaining biogenic components. They use their turf and plants to prevent ground and surface water contamination, particularly by nitrogen and phosphorus compounds [30]. From the viewpoint of ecosystem services, particular importance should be ascribed to mobile mineral nitrogen compounds and especially nitrates, which contribute to adverse environmental impact. The nitrate contamination of grassland ecosystems can be prevented by binding nitrates with the organic matter contained in the turf and above-ground biomass layers as well as through denitrification [30]. Field ecosystems do not prevent environmental contamination with biogenic components. This makes for particularly high discharges into water, especially where intensive fertilization is employed. Meanwhile, the denitrification of waterlogged grasslands and flood plains in river valleys takes place at the rate of 0.5-2.4 kg ha^{-1} of nitrogen per day [30] (for calculation purposes, the author adopted the mid-interval value of 1.5 kg N ha^{-1}). Considering that microbiological activity in the soil takes place exclusively in the growing season (ca. 180 days in a year), the prevention of nitrate contamination of water in the study area can be expected to amount to 259.7 t of nitrogen.

In addition, the biogenic components available in the soil are removed from the study grasslands together with the biomass that is harvested and used in the IFBB process. The nitrogen content of the silage procured in the Noteć River Valley is 12.3 g per $kgDM^{-1}$, i.e., 0.064 t ha^{-1} (with a yield of 5.2 t DM ha^{-1}).

Table 1. Valuation of ecosystem services in the impact area of the prospective IFBB installation in Noteć River Valley.

Service category	Biophysical value	Unit	Economic value	Unit	Service valuation for the area of 962 hectares (PLN)
Biomass production for energy-generation purposes (IFBB technology)	4.5	pelet t ha^{-1}	450.0	$PLNt^{-1}$	1,948,050.0
Carbon capture and storage	0.8	t Cha^{-1}	95.0	$EURt^{-1}$	321,056.7
Protection of soil against erosion	2.2	t ha^{-1}	116.4	$EURt^{-1}$	1,081,792.2
Water retention	180.0	m^3ha^{-1}	16.5	$EURm^{-3}$	12,546,558.9
Use of biogenic components to prevent water contamination	0.334	t ha^{-1}	539.8	$EURt^{-1}$	761,636.1
Recreational use	962.0	ha	54.1	$EURha^{-1}$	228,541.7
Total					16,887,635.6

Source: Own work based on own research (Polish zloty trading at PLN 4.3913 to the euro [47])

The economic value of the capacity of grasslands to prevent water contamination with biogenic components by binding nitrogen with organic matter (259.7 t) and biomass (61.6 t) is estimated based on the conventional water purification and treatment cost of EUR 539.8 per t^{-1} [24, 54]. The nitrogen captured by grassland ecosystems and contained in the harvested biomass in the study area was valued at PLN 761,636 per annum.

Recreational Use

An assessment of land use impacts on landscape aesthetics is central to the concept of ecosystem services within the meaning of the European Landscape Convention [40]. The valuation of the recreational use of semi-natural grasslands as an ecosystem service is a huge challenge as insufficient data is available on the popularity of the site in question for tourism. Furthermore, perceptions of the beauty and recreational value of a given area are a matter of individual taste and preferences. A Czech survey designed to ascertain the price that the respondents would be willing to pay to preserve rural landscapes made up largely of grasslands produced the amount of EUR 54.1 per ha^{-1} per annum [30]. This places the value of recreational ecosystem services in the study area of the Noteć River Valley at PLN 228,542.

Table 1 summarizes an environmental-impact-based valuation of ecosystem services within the impact zone of the prospective investment project in the Noteć River Valley. An analysis of six categories adopted to value ecosystem services in the 962 hectares of semi-natural grasslands to be utilized as a resource base for an IFBB installation produced the amount of PLN 16.9 million per annum.

Fig. 3 depicts the breakdown by estimated value of individual ecosystem services in semi-natural grasslands in the area of the prospective IFBB installation in the Noteć River Valley. The dominant share (74%) in the total value of services in the study ecosystem can be ascribed to grasslands acting as a natural water retention system.

The use of the IFBB technology in the Noteć River Valley will additionally fit into the plan of protecting the Natura 2000 areas established by the Regional Environmental Protection Directorates of Poznań and Gorzów Wielkopolski [55-56]. In addition to the active protection of natural habitats, plant and animal species, and their habitats – all of which are mandatory – the project will include extensive harvesting and the use of permanent grasslands in keeping with the requirements of the agri-environmental package.

Conclusions and Discussion

The deployment of innovative technology in the area comprising renewable energy sources is a complex process [57]. The use of biomass from environmentally valuable areas such as semi-natural grasslands makes the implementation of the IFBB technology in Poland even more of a challenge. Prospective investors and other concerned parties seeking to popularize the solution in market conditions for the above-described purposes may find it helpful to employ a novel approach to analyzing the technology implementation potential (implementation

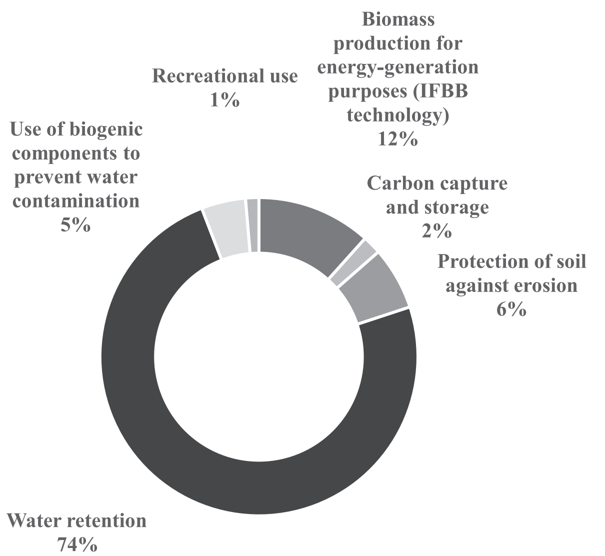

Fig. 3. Breakdown by estimated value of key ecosystem services in the impact area of the prospective IFBB installation in the Noteć River Valley. Source: Own work based on own research

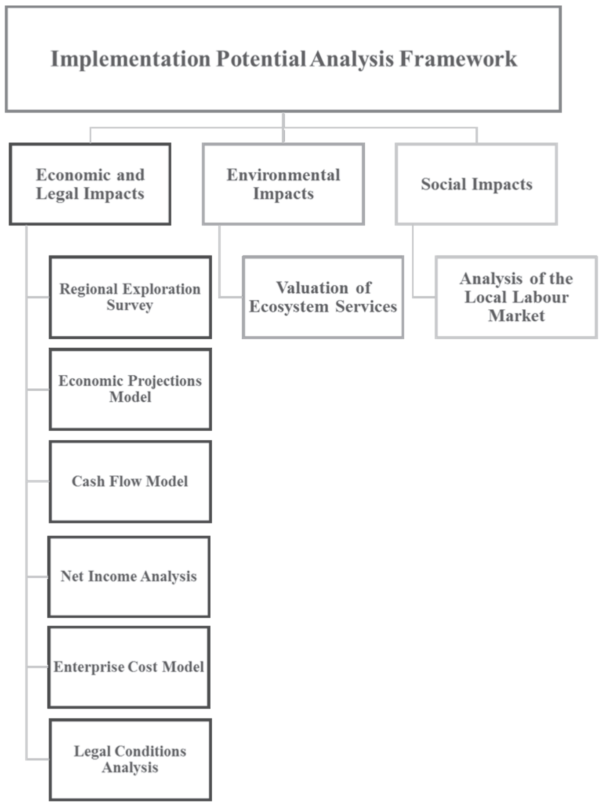

Fig. 4. Framework for assessing impacts of implementing an innovative renewable energy technology in environmentally valuable areas. Source: Own work based on own research

potential analysis framework) [58]. Ecosystem services valuations are a key part of environmental impact assessment. The framework additionally relies on assessing economic, legal, and social impacts (Fig. 4).

The uniqueness of the authors' approach to assessing the potential of the technology in question lies in its combination of a regional exploration survey and commonly-used investment evaluation instruments. The questionnaire survey is central to rolling out projects in environmentally valuable areas. The data captured through the survey is used at all subsequent stages of assessing prerequisites for use of the technology (including environmental and social factors). As some of the data is site specific, it is possible to formulate model assumptions and better understand project profitability. This differentiates the approach from the more traditional project assessment methods that rely on net present value analysis. This makes the approach particularly useful for projects that include an element of environmental protection. In identifying prerequisites for the deployment of the innovative technology in environmentally valuable areas, one additionally assesses the legal environment of a prospective project and its social impacts.

The ecosystem service valuation method presented in this article may be further enhanced with a life cycle assessment (LCA) of the technology in question. Such an assessment provides essential insights and identifies flows between the resources used, the energy generated, the products produced, and the emissions released at each stage of the production process [59-60]. LCA is a widely-recognized quantitative tool for assessing environmental impacts. Yet the scope of its assessment is limited to potential impacts (based on general impact models). What LCA does not do is help identify the implications of such impacts for the specific ecosystems on which a given organization relies [42]. LCAs offer entrepreneurs knowledge of the emissions or waste volumes that they need to cut in order to reduce their environmental footprints. However, LCA does not support decision-making, as it stops short of quantifying the impacts on a specific ecosystem at the place and time in/at which specific production takes place. This is particularly critical for IFBB technology, whose operation depends on the good condition of environmentally valuable grasslands. Any adverse changes to such grasslands would erode the value of the company that employs the technology while creating additional risks.

A significant challenge for enterprises that arises in utilizing the LCA method lies in its relative uselessness for selecting priorities for environmental protection efforts and its view of profit maximization as the primary business pursuit [43]. This makes it a poor aid for reaching informed decisions that are consistent with the principles of sustainable growth, as argued by Comello [43] based on the cases of Webcor Builders and Walt Disney Imagineering. Due to these limitations of the LCA method, the article has adopted an ecosystem services valuation method that is centered on assessing environmental impact from the entrepreneur's perspective.

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