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CARBON SEQUESTRATION IN FOREST VALUATION[1]

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Abstract

Strong links between the condition of the environment and the economy have recently resulted in a number of actions aiming to implement environmental considerations in economic calculations. This is accompanied by the development of the concept of ecosystem services, characterizing the benefits that the environment provides humankind with. The identification of these services is reflected in their economic values. Hence, the concept of the valuation of ecosystem services. Therefore, if the service provided by the environment takes on a financial value, we can consider it as income from the property containing the analyzed ecosystem. Of course, in order to speak in practice of the income approach in the valuation of such properties, there must be actual financial flow as income for the real estate owner. However, in the era of big economic changes and the implementation of a number of financial instruments (e.g., subsidies for a particular use of property, trade of CO^2 emission rights), it

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seems reasonable to consider the possibility of property valuation by the valuation of ecosystem services.

A part of this research focused on a service of forest ecosystems service that is carbon sequestration. The selection was made due to the implementation of the climate policy at the European level and its association with the trade of CO^2 emission rights. The analyses were performed for two test sites characterized by different determinants (composition of species in the tree stand, age of the stand, degree of compactness of the tree stand, etc.). The low level of difficulty of the test methods used enables non-experts (persons with no qualifications in forestry) to carry out valuations themselves. The research is a contribution to the debate on the possibility of accounting for carbon sequestration in forest property valuation based on the income approach, but the issue still requires clarification of certain elements.

1. Economy and the environment

The development of human activity is increasingly accompanied by a noticeable relationship between the state of the environment and the economy. All countries, both in the past and today, have been relying on natural resources, opportunities for their natural renewal, and the self-cleaning capacity of the environment. Some communities exceed the self-reproduction abilities of the environment, which leads to the degradation or loss of the environment. In extreme cases, this may even lead to the collapse of an entire civilization within a given area, an example being the case of Easter Islands inhabitants (GOOD, REUVENY 2006).

People have been exploiting the resources of our planet for years. The burning of coal, oil and natural gas in order to obtain energy involves the emission of huge amounts of carbon dioxide into the atmosphere. Problems associated with environmental degradation were not observed until the second half of the twentieth century. The result of these processes is the present-day climate changes (ALFARO et al. 2014). With regard to CO^2 emissions, the mitigation of the negative effects of this process can be carried out in two ways. One of them is by the reduction of emissions, and the second - the accumulation and sequestration of carbon dioxide. Limitation of emissions is associated with costly investments in technology, the accumulation of gases, and developing alternative sources of energy. Another, technically simpler way, is to increase CO^2 accumulation and absorption by plants.

1.1. Ecosystem services and their valuation

Rational and sustainable management becomes a balancing act between the available resources so as to achieve the highest quality of life ensured to the next generation, with at least the same conditions for development. This also applies to natural resources and the environment. However, there have been several examples in the past of local communities attaching great importance to one factor, which led to the degradation or loss of many resources. Experience shows that in today's economy, the desire to improve economic conditions often leads to the loss of environmental resources. For this reason, it was necessary to reflect environmental determinants in the economic calculations, in order to balance the use of the available resources in an effective way (ZYLICZ 2004).

One of the means of implementing environmental aspects into economic calculations is the concept of ecosystem services. According to this approach, we can discern the benefits that ecosystems have to man. Depending on the assumed classification, several groups of ecosystem services can be distinguished. According to the division of the Millennium Ecosystem Assessment, we can speak of supporting, provisioning, regulating and cultural services (KRONENBERG 2012). Carbon sequestration, which is analyzed in this article, is attributed to regulating services in the field of climate regulation. We can look at this issue more broadly. Depending on the type of land use, we deal with a variety of ecosystems, and thus, also with a variety of services provided by them. The identification of these services is crucial, especially in the context of planning land use change. The elimination of an ecosystem and replacing it with another form of use will result in the elimination of the provided services. The decision-making process of changing the property use should, therefore, take into account the values which are lost due to ceasing to provide given ecosystem services (KUMAR, WOOD 2012).

Including ecosystem services in economic calculations encompasses, in addition to their identification, the necessity of expressing them in comparable units. For this reason, it was essential to express ecosystem services in financial terms, opening up new opportunities for the valuation of these services. Two groups of methods of valuating environmental resources can be distinguished, i.e. direct and indirect. Direct assessment methods include the hedonic price method, the method of conditional valuation, and the travel cost method. Indirect methods include the substitution method, interaction-effect method, cost of lost opportunity method, compensation method, replacement method, and preventive method (FIEDOR et al. 2002). The valuation of ecosystem services is an issue that is significantly connected with the uncertainty of the resulting accuracy of the assessment. The valuation of the components of ecosystem services is based on subjective methods of assessing the environment, which leads to a very limited opportunity of verifying the proper magnitude of the result. Such techniques may include the hedonic pricing method, which is strongly associated with sensitivity and the respondents' sense of aesthetics. Some of the methods are sensitive to the proper timing of the survey. An example of this is the travel cost method of valuation of aesthetic and recreational activities, where, depending on the weather conditions, we deal with a different intensity of tourist traffic. In the case of others, there is the problem of the lack of a comparative base or its insufficiency. The valuation of some ecosystem services is made only after they have been lost. Serving as an example is the elimination of pollination services made by bees, and the need to bear the expenses of substitution operations. It is estimated that the service of pollination on a global scale for fruit trees alone is at the level of 153 billion € per year (MELATHOPOULOS et al. 2015). Many studies have been conducted in terms of valuating forest ecosystem services (GUITART, RODRIGUEZ 2010; TAO et el. 2012; MOOG, BOSH 2013; BARTCZAK 2015; TORRES et al. 2015), but only a few of them relate to existing or proposed financial mechanisms, which could have an influence on the profits of property owners. Finally, some of the services have not received a developed measurement method. All this limits the popularity of valuating environment components or ecosystem services, and does not gain the trust of society. However, there are also some groups of services that are closely related to the functioning economy and provide a reliable basis for their valuation (e.g. recreational services, educational services, provisioning services of raw materials, etc.).

1.2. Legal and financial mechanism

Regardless of the beliefs that local communities hold regarding the reliability of the valuation of ecosystem services, their popularization is mostly supported by real financial instruments. This, however, depends on the implementation of development policies in the form of legislation.

Poland, in accordance with the climate and energy package and ratified Kyoto Protocol, is committed to:

- reducing (by 2020) greenhouse gas emissions by 20% below the levels from 1990,
- increasing, to 20%, the share of energy from renewable sources in the total consumption in 2020,
- increasing energy efficiency by 20% with respect to the predictions for 2020,
- increasing, to 10%, the share of energy from renewable sources (biofuels) in transport (Kioto Protocole … 1997).

Reductions in greenhouse emissions in Poland so far have included, among others, energy combustion -34%, the energy industry -36%, the manufacturing and construction industry -45.1%, and agriculture -30.6% (UN 2011). An increase in emissions has been reported in the transport sector +99.6%, and as a result of changes in land use (LULUCF) +248.7% (UN 2011). This does not change the fact that the Polish economy is one of the biggest emission producers in the EU. Greenhouse gas emissions per capita in Poland are higher than in the other 11 EU countries with higher income per capita. Official government predictions anticipate that primary energy demand will have increased by a total of 21% by 2030. The largest increase in energy demand will be after 2020. CO^2 is expected to gradually increase to approx. 280 million tons in 2020. By 2030 the emissions will exceed 300 million tons (MG 2009). In 2014, the European Council appointed a new ambitious climate policy. The Brussels agreement provides that the European Union is to have reduced CO^2 emissions by at least 40% by 2030 as compared to 1990. The agreement implies that the share of energy from renewable sources in total electricity consumption will reach 27% in 2030 (EC 2014).

The strategic document, defining the main objectives and measures of reducing the impact of the electro-power sector on the environment, increasing energy efficiency, introducing nuclear energy and developing renewable energy and biofuels, is Poland's Energy Policy to 2030. The main objective of the policy is to maintain "zero-energy" economic growth. National legal, financial and organizational mechanisms, implemented or prepared for implementation, which directly or indirectly stimulate the reduction of emissions include, among others: tradable certificate systems that promote renewable energy and co-generation as well as the promotion of biofuels by means of exemption from excise duty, concession of corporate income tax, promoting energy crops, and support for investing in biofuel-powered vehicles and the preferential treatment of such vehicles. These mechanisms are also used to implement the climate provisions of such development policies as: *The Medium-Term National Development Strategy 2020; Strategy for Innovation and Efficiency of the Economy; Strategy for Sustainable Rural Development, Agriculture and Fisheries; Strategy for Energy Security and Environment;* as well as the *National Program for the Development of a Low-Carbon Economy*.

One of the key instruments for implementing energy and climate policies is setting CO^2 emission limits. The market for the trading of CO^2 emission rights is to establish a decreasing annual limit of total emissions in industrial sectors with high emissions of greenhouse gases. Within this limit, companies can buy and sell emission rights according to their needs. Each entitlement gives the right to emit one ton of carbon dioxide. The market sets benchmarks for specifying the unit value of CO^2 emissions released into the atmosphere (EU 2003).

1.3. Carbon sequestration in the income approach

The process that counteracts CO^2 emission is carbon uptake by plants and the release of pure oxygen into the atmosphere. This service, provided by plants, is called carbon sequestration. The benefit can be measured in financial values by making use of CO^2 emission rights on the emission allowance market. On the basis of measuring carbon contained in the analyzed forest real estates and relating it to their financial value (the value of accumulated carbon), we are able to measure the ecosystem service of carbon sequestration. Therefore, if the service provided by the environment becomes a financial value, we can consider it as income from the property which the analyzed ecosystem is located in. Of course, in order to talk about the income approach to the valuation of such a property in practice, there must be actual financial flow. The property owner must be paid for the service. It is true that this is not the case at the moment. It is also not clear what the European or world economy will look like in a couple of years, and whether the service of absorbing carbon from the atmosphere will be valued in the same way as emitting CO^2 into the atmosphere. However, it seems reasonable to consider the possibility of carrying out real estate valuation using the income approach through the valuation of services provided by the ecosystem located on the property. In the case of introducing a financing instrument for carbon absorption from the atmosphere by plants in the future, property experts must be ready to meet new economic determinants in this regard.

2. Measurement of CO^2 sequestration methodology

The aim of the present study was to assess the potential profit coming from carbon dioxide absorption and carbon sequestration in the biomass of forest ecosystems. The empirical data which was used for this analysis comes from the "D&B" Field Research Station of the Laboratory of Evaluation and Assessment of Natural Resources, located in the Forest District of Tuczno in Western Pomerania. For part of the present research, measurements were carried out on two study sites within the "Martew" research facility (SZYSZKO, RYKLE 2002). The location of these sites has been shown on an orthophotomap below (Fig. 1). The two sites are characterized by different determinants. The first measurement site contains a 90-year-old beech forest, which grew from the undergrowth after cutting down a 130-year-old pine stand. In the second site, there is a 40-year-old pine stand. The different determinants of the analyzed sites made it possible to refer the results of the conducted research to varied conditions at the local level. The test methods which were used are characterized by a low level of difficulty, thus the valuation can be done by persons with no qualifications in forestry. Measurement locations applied to three elements: trees, undergrowth (pine) or saplings (beech) and the litter layer.

2. 1. Measurement of trees

Each of the tested tree stands was limited to a test area measuring 25m x 25m for pines and 25m x 50m for beeches. The measurements covered such elements as the average breast height diameter (DBH) of trees, the number of trees per 1 hectare, the average height of trees, the average annual growth of the trunk, the average volume of the trunk of a single tree, the average volume of the trunks of all trees per 1 ha, the density of trees per 1 ha, and the biomass of trees per 1 ha.

The DBH measurement consisted of measuring the diameter of the trees, i.e. the diameter at breast height (at a height of 1.3m above the ground). The tested trees were to have a diameter of more than 7cm. The tool used during this process was a caliper. The measurements made it possible to obtain the number of analyzed trees in each stand as well as the average diameter at breast height.

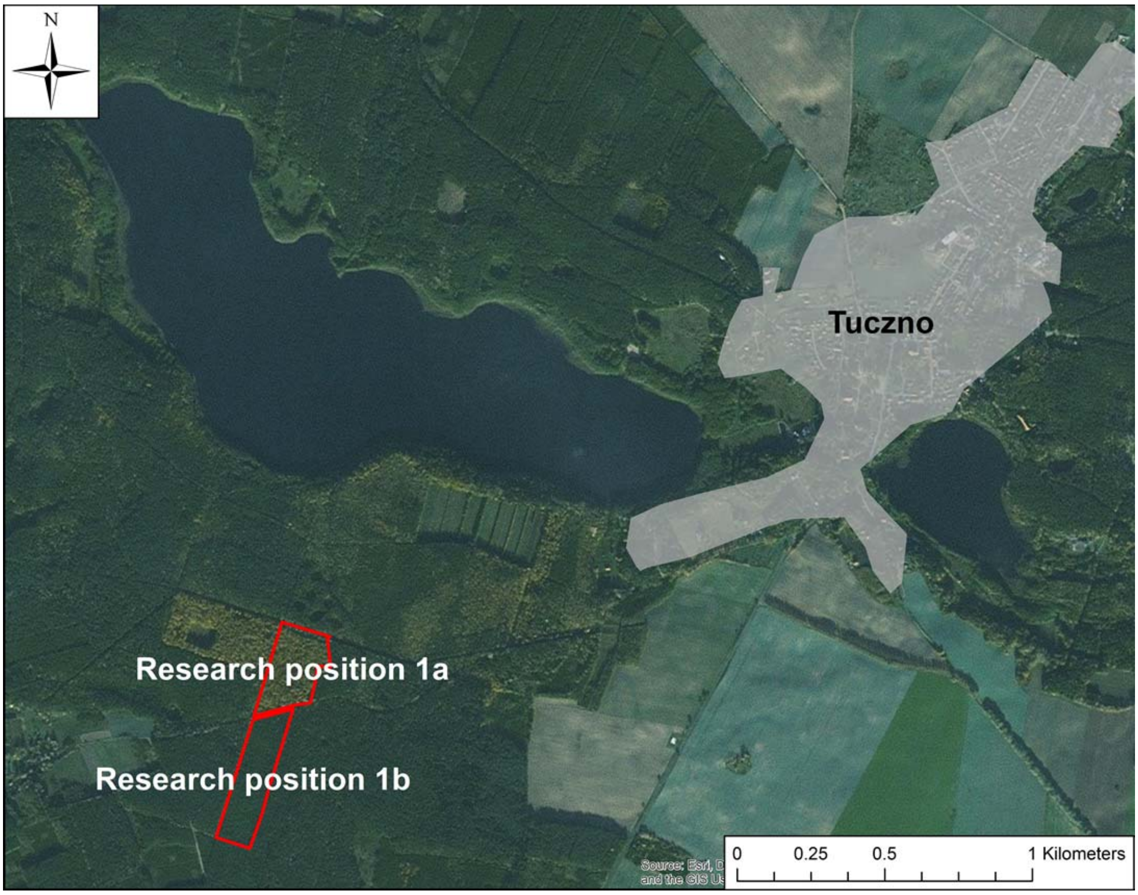

Fig. 1. Location of study sites. *Source*: own study based on data from ESRI.

Formula used to calculate the average DBH:

$$p_{śr} = \frac{p_1 + p_2 + \cdots + p_n}{n} \tag{1}$$

where:
$p_{śr}$ – average DBH,
$p_{1 \ldots n}$ – height of the tested trees,
n – number of tests.

Formula used to calculate the number of trees per 1 ha:

$$L_{ha} = \frac{P}{p} \times L_o \tag{2}$$

where:
L_{ha} – number of trees per ha,
P – reference unit - 1ha expressed as a 10,000 m^2,
p – area of the test stand in m^2,
Lo – number of trees in the test unit.

The measurement of the average height of trees for each of the stands was performed on 10 trees which were representative of the average parameters in the given stand. Measurements were taken using an altimeter and geodetic tape, measured at a distance of 15 meters from the tree.

Formula used to calculate the height of the trees:

$$h_{śr} = \frac{h_1 + h_2 + \cdots h_n}{n} \quad (3)$$

where:
$h_{śr}$ – average height,
$h1 \ldots n$ –sampled tree height,
n – number of tests.

The average annual growth of the trunk was measured using a Pressler drill. The basis for the specification is a tree borehole, which shows the annual tree growth based on the sum of the thickness of annual growth over the past five years.

Formula used to calculate the average annual growth of a trunk:

$$pr_{śr} = \frac{pr_1 + pr_2 + \cdots + pr_5}{5} \quad (4)$$

where:
$pr_{śr}$ – average annual growth of the tree,
$p_{1 \ldots n}$ – thickness of tree growth in a year,
5 – number of years of estimated growth.

The results of the measurements have been summarized in the table below (Tab. 1).

Table 1

Summary of measurements and calculations for trees - part A

Study site	p - Area of the test stand [m2]	L_o - Number of trees in test unit	L_{ha} - Number of trees per ha	$h_{śr}$ - Average tree height (m)	$p_{śr}$- Average DBH (m)	½ $p_{śr}$ - Average radius (m)	$pr_{śr}$ - Average annual growth of tree (cm)
1a	1250	17	136	28.1	0.36	0.18	0.45
1b	625	75	1200	19.3	0.18	0.09	1.06

Source: own study.

The average volume of the trunk of a single tree was calculated on the basis of the cone volume formula:

$$V = \frac{\pi \times r_{śr}^2}{3} \times h \quad (5)$$

where:
π = 3.1415927,
V – average volume of the trunk of a single tree,
$r_{śr}$ – average radius of the tree (½ $p_{śr}$),
h – average tree height.

The average volume of the trunks of all the trees on 1 ha is the product of the average volume of a single tree trunk (V) and the average number of trees per hectare:

$$V_{ha} = V \times L_{ha} \quad (6)$$

Determining the thickness of trees (M) includes summing the volume of trees per 1 ha and taking 50% of this volume, with 30% being the volume of the roots, and 20% - the volume of the branches. It can be expressed by the formula:

$$M = 1{,}5 \times V_{ha} \quad (7)$$

The tree biomass per hectare (B) is the product of the volume of trees per 1 ha (M) multiplied by a coefficient of 0.7. This coefficient allows one to calculate the volume, expressed in m^3/ha, per biomass, expressed in t/ha.

$$B = M \times 0.7 \tag{8}$$

The results of these measurements have been summarized in the table below (Tab. 2).

2. 2. Undergrowth and sapling measurement

Measurements of the undergrowth and saplings (trees with a diameter of less than 7cm, the term undergrowth applies to the pine stand and saplings to beech) were performed in random areas measuring 4m x 4m. These included counting all the trees with a diameter of less than 7 cm, and weighing selected medium-sized trees. At the stage of compiling the data, the mass of the average undergrowth and saplings was converted to the value of coal under the same assumptions as in the main stand.

Table 2

Summary of measurements and calculations for trees - part B

Study site	*V* - Average volume of the trunk of a single tree (m3)	V_{ha} - Average volume of the trunks of all trees on 1 ha (m3/ha)	*M* - Thickness of trees (m3/ha)	*B* – Tree biomass per 1 ha (t/ha)
1a	0.95	258.4	387.6	271.32
1b	0.16	196.45	294.68	206.28

Source: own study.

Formula used to determine the number of trees per ha:

$$L_{ha} = \frac{P}{p} \times L_o \tag{9}$$

where:
L_{ha} – number of trees on 1 ha,
L_o – number of trees in a test unit,
P – reference area (10,000 m²),
p – area of test unit equal to 16 m².

The tree biomass (B) is the product of the mass of an average tree and the number of trees per hectare:

$$B = \frac{m \times L_{ha}}{1000} \tag{10}$$

where:
m – mass of an average undergrowth or sapling,
1000 – coefficient converting units of kilograms into tons.

The results of the measurements and calculations of the undergrowth and saplings have been summarized in the table below (Tab. 3).

Table 3

Summary of measurements and calculations for undergrowth and saplings

Study site	L_o - Number of trees in test unit (4m x 4m)	*m* - Mass of average undergrowth or sapling (kg)	L_{ha} - Number of trees on 1 ha	*B* – Tree biomass per 1 ha (t/ha)
1a	62	0.25	38750	9.69
1b	14	0.3	8750	2.63

Source: own study.

2. 3. Measurement of litter

Three random areas measuring 50cm x 50cm were analyzed within the study sites. Litter at these sites was removed, exposing mineral soil, and then weighed using portable scales with an accuracy of 1 dag. The weight of the litter was the basis of calculating its biomass per 1 hectare. The litter biomass was calculated using the following formula:

$$B = \frac{m_{śr} \times 10000}{p} \times \frac{1}{1000} \tag{11}$$

where:
B – litter biomass per 1 ha,
$m_{śr}$ – average litter biomass of tested area (kg),
p – size of test area,
1/1000 – coefficient converting mass units from kilograms to tons.

The results of the measurements and calculations of the litter biomass have been shown in the table below (Tab.4).

Table 4

Summary of measurements and calculations for litter

Study site	$m_{śr}$ - Average litter biomass in test area 0.5m x 0.5m (kg)	B - Litter biomass per 1 ha (t/ha)
1a	1.250	50.0
1b	2.2833	91.3

Source: own study.

2. 4. CO² equivalent

Calculating the amount of accumulated carbon dioxide requires necessary data in the form of the previously calculated biomass of the main stand, saplings, undergrowth and litter. The corresponding CO² can be defined using the atomic mass of carbon and oxygen, and on the basis of the amount of carbon absorbed by it. It can then be used to determine the value of the service performed by the forest ecosystem.

The first step was calculating the CO² equivalent for tree stands, undergrowth and saplings. Carbon represents approximately 50% of the mass of a tree (KOKOCINSKI 2002). The coefficient 3.67 helps to convert the total amount of carbon into the amount of carbon dioxide accumulated, and results from the share the atomic mass of carbon has in the mass of carbon dioxide particles.

$$\frac{44u}{12u} \sim 3.67 \tag{12}$$

where:
44u – atomic mass of carbon dioxide particles,
12u – atomic mass of carbon.

$$A_{CO_2} = \frac{B}{2} \times 3.67 \tag{13}$$

where:
B – biomass (t/ha)
A_{CO2} – amount of accumulated carbon dioxide (t/ha)

Carbon dioxide is also accumulated in the litter. In the case of litter, the content of carbon is different than in the case of timber. In the study sites, the share of coal in litter is 30% (SZYSZKO, RYKLE 2002). On this basis, the calculation of the CO² equivalent of litter applies the formula:

$$AA_{CO_2} = 0.3 \times 3 \times 3.67 \quad (14)$$

Table 5

Biomass and carbon dioxide

Study sites	Trees		Undergrowth/saplings		Litter	
	Biomass (t/ha)	Carbon dioxide (t/ha)	Biomass (t/ha)	Carbon dioxide (t/ha)	Biomass (t/ha)	Carbon dioxide (t/ha)
1a	271.32	497.87	9.69	17.78	50.0	55.05
1b	206.27	378.51	2.63	4.82	91.3	100.56

Source: own study.

The results of the calculations of biomass and accumulated carbon dioxide in trees, undergrowth/saplings and litter have been shown in the table below (Tab. 5).

2. 5. Value of ecosystem service

The analysis deliberately did not take into consideration the value of timber calculated by multiplying the thickness of the trees and average price of timber reported in the *communications of the President of the Central Statistical Office,* but only the price per ton of carbon dioxide at daily rates. The average euro exchange rate on the given day was established on the basis of data from the Polish National Bank. The calculations were based on the following assumptions:

- the price of a ton of carbon dioxide according to rates as of July 4, 2014 (last day of measurements) was 6.11 euro,
- the average exchange rate of the euro on July 4, 2014 was 4.1435.

The results of the calculations concerning the service of ecosystem have been shown in the table below (Tab. 6).

Table 6

Amount and value of carbon dioxide accumulated in the study sites

Study Site	Carbon dioxide accumulated up to the day of measurement							
	Trees		Undergrowth /saplings		Litter		**Sum**	
	Amount (t/ha)	Value (PLN)	Amount (t/ha)	Value (PLN)	Amount (t/ha)	Value (PLN)	**Amount (t/ha)**	**Value (PLN)**
1a	497.87	12 604.47	17.78	450.13	55.05	1393.69	**570.70**	**14 448.29**
1b	378.51	9582.66	4.82	122.03	100.56	2545.85	**483.89**	**12 250.54**

Source: own study.

3. Summary and conclusions

The presented results demonstrate the potential of the existing as well as newly emerging forest ecosystems. Carbon sequestration in the study sites was estimated at the level of 12,000 to almost 14,500 PLN per hectare. It should be noted that in second study site, the forest ecosystem is younger than half of its' predicted life, but already the value is relatively high. The value of accumulated carbon dioxide may be an additional source of income from which the forest owner benefits. Carbon sequestration is extremely important, both from the point of view of environmental protection and the economy. The current legal regulations concerning the rights to carbon dioxide emissions are inconsistent and not clearly defined. So far legislators have not undertaken the task to standardize the legal definition of CO^2 allowances in any of the documents ratified by Poland. Furthermore, there is a lack of willingness and agreement among countries throughout the world to accept the absorption of

CO^2 as an alternative to its reduction. The implementation of Poland's CO^2 absorption system through carbon sequestration would have many benefits. It would mean obtaining some additional profit, which gives opportunity for further development and a positive impact on the economy. This mechanism, however, would have to be used in a broader context, i.e. not based exclusively on an independent internal system but on an international one – as part of a global policy for sustainable development. However, introducing such a possibility requires appropriate instruments for the implementation and monitoring of CO^2 absorption and accumulation by forest ecosystems.

Assessing the value of carbon accumulated by forest ecosystems is unambiguous. The Kyoto Protocol has created the possibility to take into account carbon accumulation by forests, however, many elements of implementing such calculations continue to remain an open topic. In the discussion about the possibility of applying this mechanism in the valuation of real estate using the income approach, the problem regarding the time of ecosystem service or rates to be adopted in determining their value (also taking into account the variability of this rate in time) should be clarified. So far, carbon sequestration can be calculated only as non-market value. If this mechanism were to be included in a global accounting system, the value of CO^2 absorption could be treated as a market value. In the income approach, the pension account method (*Pol. rachunek rentowy*) allows for benefits from real estate to be included (WOŚ 2010). In the case described in the paper, benefits from carbon sequestration are used for this purpose. Dividing those benefits by a percentage rate gives a value that could be used in forest appraisal. However, the intention of the authors was only to investigate the possibility of the application of forest measurement and the presentation of the results in order to initiate a discussion about including carbon sequestration in forest property valuation based on the income approach.

The reduction of CO^2 emissions, resulting from the need to implement the climate policy, involves considerable financial investments. A solution to reducing emissions may be CO^2 accumulation by forest ecosystems. Poland has a great potential in infertile soil that can be afforested. The area reaches 2 million hectares. Thus, for example, the existing forest ecosystems could be used and benefits from property used in this way gained for 100 years (average harvest year for pines is 100; for beeches - 120-140 years). A necessary factor in reaching this goal is achieving the willingness and agreement of different countries throughout the world to accept CO^2 absorption as a real method for its reduction. Only then will the service provided by forests obtain a financial dimension and be the basis for the valuation of forests in the income approach. Specifying a value for ecosystem services could provide new valuable material in the development of property value maps for purposes other than taxes, which has been the subject of research in recent years (CELLMER et al. 2014). Cartographic material in this regard would be helpful in spatial management, e.g. in making decisions regarding afforestation. Synergy between these plays an important role in creating sustainable land administration systems (ZROBEK, ZROBEK 2008; WILLIAMSON et al. 2010).

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