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RESEARCH ARTICLE

# The Relationship Between the Wood Biomass and the Formation of Coals

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**ABSTRACT**

The present study proved a similarity between wood, as renewable resource, and peat/brown coals as fossil fuels, all three being important sources of energy. The study was done in the oligotrophic peat pond Poiana Stampei, an important bog in the Dornelor Depression located in North West Romania. A floristic survey on herbaceous and woody species was done. Peat samples and dead branches from the six woody species were taken. The calorific capacity of the wood was determined using the Bomb Calorimeter (Model-IKA C2000), the carbon content was measured with a CE Instruments EA-1110 CHNS-O dispositive. The carbon content of wood, approximately 50%, is higher than that of peat, which does not exceed 40%; it being able to grow in favorable conditions for the fossilization process, the concentration in the wood in the organic matrix of the peat being 58%. The calorific value of wood (21,149 ± 1976 Kj/kg) is higher than that of peat (14,350 Kj/kg) and closer to that of lignite (28,470 Kj/kg). Carbon-enriched wood represents an alternative solution to brown coals, which are non-renewable resources.

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## 1. Introduction

Biomass is an important source of energy coming from solar radiation, fixed and stored by plants through the process of photosynthesis, this being also transmitted to animals that are consumers of vegetable biomass (Gheorghe, 2024a). The biomass produced and stored in large quantities during the Carboniferous period and in smaller quantities in the Cretaceous, was subjected to fossilization processes, ultimately leading to fossil fuels (coal, oil, methane gas) (Măldărescu, 1987). The main change undergone by the biomass in the fossilization process is the increase in carbon content. The use of fossil fuels in the industrial era led to the development of an industry for processing and creating equipment in which the finished products are used to produce energy. This know-how required an important intellectual and financial effort that cannot be ignored in the context of climate change; in an attempt to give up fossil fuels, because their burning is considered as one of the main causes (Ambrose, 2020). For now, alternative energy sources, globally, cannot ensure the production of energy generated by the use of fossil fuels. In 2019, the global energy produced from renewable sources represented only 7%, registering an increase of only 4% compared to 2000, the majority of 93% coming from the use of fossil fuels (Gheorghe & Strat, 2023). A sudden change of conventional energy sources with renewable alternative sources is not possible. That, is why it is useful that in the following years the two major problems that exist in the production of energy from fossil fuels are solved: *i)* their resources are non-

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renewable; *ii)* the technology for obtaining energy is contributing to the green-house effect. Reducing pollution can be achieved by improving technologies in the sense of increasing transformation yields, the use of less polluting processes the of use waste and noxes as resources for secondary technologies. For the time when fossil fuel resources will be in collapse, a possible solution could be the transformation of current biomass into carbon-rich structures similar to fossil fuels. The current biomass variant with a high carbon content, similar to coals, is wood. The carbon content per gram of woody dry biomass varied between 0.498 mgC/g d.s. and 0.578 mgC/g d.s., the greatest content being in sessile oak and the lowest in willow (Gheorghe, 2024b). Half of the woody biomass is represented by carbon, the cell wall of the cells in the growth rings is thick and mainly composed of lignin and cellulose (Gheorghe & Ţopa-Stan, 2007). Coal is a solid, black, readily combustible fossil fuel that contains a large amount of carbon-based material - approximately 50% of its weight (Affolter & Hatch, 2015; Wolfson, 2012). Coal (from the Old English term col, which has meant "*mineral of fossilized carbon*" since the 13th century) is a combustible black or brownish-black sedimentary rock usually occurring in rock strata in layers or veins called coal beds or coal seams (Măldărescu, 1987; Wagner, 2021). The harder forms, such as anthracite coal, can be regarded as metamorphic rock because of later exposure to elevated temperature and pressure. Coal is composed primarily of carbon along with variable quantities of other elements, chiefly hydrogen, sulfur, oxygen, and nitrogen. A fossil fuel, coal forms when dead plant matter is converted into peat, which in turn is converted into lignite, then sub-bituminous coal, after that bituminous coal, and lastly anthracite. This involves biological and geological processes that take place over a long period (Wagner, 2021).

**Table 1.** Content of chemical elements in different types of coal (Wagner, 2021) (Măldărescu, 1987) modified by Gheorghe and Benciu (2025).

| Coal type | Volatiles % | C - Carbon % | H - Hydrogen % | O - Oxygen % | Heat content kJ/kg |
|---|---|---|---|---|---|
| Peat | 63-69 | 30-40 | 5-4.8 | 36-20 | <15,000 |
| Lignite (brown coal) | 45–65 | 60–75 | 6.0–5.8 | 34-17 | <28,470 |
| Flame coal | 40-45 | 75-82 | 6.0-5.8 | >9.8 | <32,870 |
| Gas flame coal | 35-40 | 82-85 | 5.8-5.6 | 9.8-7.3 | <33,910 |
| Gas coal | 28-35 | 85-87.5 | 5.6-5.0 | 7.3-4.5 | <34,960 |
| Fat coal | 19-28 | 87.5-89.5 | 5.0-4.5 | 4.5-3.2 | <35,380 |
| Forge coal | 14-19 | 89.5-90.5 | 4.5-4.0 | 3.2-2.8 | <35,380 |
| Non baking coal | 10-14 | 90.5-91.5 | 4.0-3.75 | 2.8-3.5 | 35,380 |
| Anthracite | 7-12 | >91.5 | <3.75 | <2.5 | <35,300 |
| Graphite | 4-7 | 95-98 | <2.5 | <1.75 | 3,280,800 |

With the exception of lignite in which it is 0.5%, in the rest of the coals the sulfur content is approximately 1% (Măldărescu, 1987).

The carbon content in coal varies from 30% in peat to 98% in graphite. Peat contains 30 to 40 carbon, some amount of volatile matter, and a lot of moisture (Table 1). The organic matter present in peat comes from herbaceous plants; whose cells have a thin cell wall, therefore the amount of lignin and cellulose is low, also the carbon content is reduced. That's why some researchers such as Wagner (2021), consider the peat to be a precursor of coal. The carbon content in peat (between 0.325 mgC/g d.s. - 0.452 mgC/g d.s is lower than that in wood (between 0.498 mgC/g d.s. - 0.578 mgC/g d.s) For these reasons the heating capacity of peat is comparatively low.

At various times in the geologic past, the Earth had dense forests in low-lying wetland areas. Due to natural processes such as flooding, landslides, runoff on the slopes, these forests were buried underneath different sediments. As more and more other new layers deposited over them, they were compressed, the pressure on them increasing significantly. In relation to the pressure, the temperature also increased significantly as the dead organic matter sank deeper and deeper. Geothermal gradient is the crust temperature rises with depth due to the heat flow from the much hotter mantle; away from tectonic plate boundaries; this temperature rises in about 25–30 °C/km of depth near the surface, in the continental crust almost 1 degree C˚ for every 30 m lowered in depth (Fridleifsson et al., 2008).

Due to increasingly harsh conditions (lack of oxygen, acidic pH, high temperature, high pressure), as the process continued the plant matter was protected from biodegradation and oxidation, usually by mud or acidic water. The lack of decomposition and mineralization of dead organic matter trapped the carbon in immense peat bogs that were eventually covered and deeply buried by sediments. Under high pressure and high temperature, dead biomass was slowly converted to coal. As coal contains mainly carbon, the conversion of dead biomass into coal is called carbonization (Măldărescu, 1987).

The elimination of oxygen and hydrogen in the coal metamorphosis processes is due to the emissions of the $N_2O$ (nitrous oxide) and $CH_4$ (methane) emissions and is challenging because of the complex co-action of many bio-geo-chemical factors (Pärn et al., 2015).

Although coal is identified in strata beginning in the Precambrian (the period before land plants), with the exception of the Permian-Triassic coal gap where coal is rare, most resources are present in the Carboniferous strata, the period characterized by the first large trees (Măldărescu, 1987).

Within the scope of the study, it was tried to make a comparison between the carbon content in wood and in two types of coal: peat and brown coal.

## 2. Materials and Methods

### *2.1.* Study Site

During the Carboniferous period, most of Romania's surface was an old seabed, that's why the coal reserves, with the exception of peat, are grouped in South-West Romania. Peat is found in many areas, in the depressions of the Carpathian Mountains, one of the most important being the Dornelor Depression located in North West Romania. In this depression there are several peat oligotrophic ponds, some active, some from which peat is exploited, some that are protected for their biological diversity. The oligotrophic peat pond Poiana Stampei (47°17'32"N / 25°06'13"E) was chosen as the study area because it is an active bog with high biodiversity conservation values. It is a protected area of national interest that corresponds to International Union for the Conservation of Nature (IUCN) category IV (natural botanical reserve), located in Suceava county, at an altitude of 904 m, occupying an area of 681.80 ha.

### *2.2.* Sampling Methodology

A floristic survey was carried out here, in which the herbaceous and woody species were identified. With a corer, peat samples were taken up to a depth of 50 cm on a gradient starting from the center of the marsh towards its edge with a frecvency of 50 meters. The samples were separated into organic matter and branches of trees and shrubs present in this matrix of organic matter. Both the branches and the organic matter were prepared for the analysis of carbon, nitrogen and oxygen, being dried, brought to constant mass and ground. Dead branches that were not pruned from the present trees and shrubs were taken. For the species present in the tree layer (*Alnus incana, Betula humilis, Picea excelsa, Pinus sylvestris)*, five individuals were selected for each species, three fragments of dead branches were taken from each individual.

### *2.3.* Laboratory Analyses

And these were prepared for CHN analysis in the same way as the branches found in the peat and the organic matrix. The carbon content was measured with a EA 1110 CHNS-O, CE Instruments, Italian producer.

For peat and each woody species present in the forest ecosystems, the calorific capacity of the wood was determined by calorimetric methods using the Bomb Calorimeter (Model-IKA C2000).

## 3. Results and Discussion

Following the floristic survey, a total number of 73 plant species were identified, of which four trees, two shrubs, 51 herbaceous vascular cryptogams, nine biophytes and seven ferns.

In terms of Abundance-Dominance on the Braun-Blanquet scale, tree and bryophyte species and six cryptogams are dominant (Table 2).

The specific composition has not changed significantly compared to that of 2004, the number of vascular cryptogams decreasing from 78 in 2004 (Gheorghe et al., 2006) to 73 in 2024. Species richness is reduced because the substrate conditions are unsuitable for most plant species, the substrate being wet, sometimes saturated in water, making root respiration difficult, the pH is acidic (3.5-4), the nutrients are strongly adsorbed by peat particles and hardly accessible to plants. This reduced specific richness makes the adapted species have a high gravimetric abundance, the total amount of biomass being significant. The low pH, the lack of oxygen, the high humidity prevent the presence of aerobic microorganisms, thus the mineralization process being reduced or even non-existent, the dead organic matter resulting from the biomass accumulates in the form of peat.

In the matrix of organic matter originating from herbaceous plants, the carbon content was the lowest, due to a reduced content of cellulose and lignin. The carbon content in dead wood not subjected to the fossilization process is higher than that in the matrix, because the cell wall of the cells that form the wood have a higher content of cellulose and lignin. The same thing was observed by Lodygin et al. (2023), who state that: “the content of lignin in the dry ash-free matter of lichens and mosses (8–10%) is less than that in grass (15–20%), shrub and wood (20–30%) vegetation”. The highest carbon content was recorded in the woody fragments present in the peat layer (Table 3). The carbon content of wood undergoing the fossilization process is higher than that of dead wood because the conditions of high humidity, acidic pH of 3.75, and lack of oxygen prevent mineralization processes by inhibiting the activity of aerobic microorganisms. The carbon present in dead organic matter, unlike other nutrients (N, O, H), does not oxidize into $CO_2$ and does not leave the system, accumulating initially as peat and then as various types of coal.

**Table 2.** The dominant species in the vegetal layer that feed the peaty substrate.

| **No.** | **Species** | **Category of species** | **Abundance-Dominance on the Braun-Blanquet scale** |
|---|---|---|---|
| 1 | *Alnus incana* (L.) Moench | trees | + |
| 2 | *Betula humilis* (Schrank) | trees | **1** |
| 3 | *Picea excelsa* (L.) H.Karst. | trees | **3** |
| 4 | *Pinus sylvestris* (L.) | trees | **2** |
| 5 | *Ctenidium molluscum* (Mitt.) | bryophytes | **1** |
| 6 | *Mnium affine* (Blandow ex Funck) T. Kop. | bryophytes | + |
| 7 | *Orthothecium rufescens* (Dicks. ex Brid.) Schimp. | bryophytes | + |
| 8 | *Pleurozium schreberi* (Brid.) Mitt. | bryophytes | **1** |
| 9 | *Polytrichum commune* (Hedw.) | bryophytes | |
| 10 | *Ptilium crista-castrensis* (Hedw.) De Not. | bryophytes | + |
| 11 | *Sphagnum auriculatum (*Schimp.) | bryophytes | **2** |
| 12 | *Sphagnum fimbriatum* (Wils.) | bryophytes | **1** |
| 13 | *Sphagnum palustre* (L.) | bryophytes | **3** |
| 14 | *Vaccinium oxycoccos* (L.) | vascular cryptogams | + |
| 15 | *Vaccinium myrtillus* (L.) | vascular cryptogams | **1** |
| 16 | *Vaccinium vitis-idaea* (L.) | vascular cryptogams | **3** |
| 17 | *Eriophorum vaginatum* (L.) | vascular cryptogams | **3** |
| 18 | *Andromeda polifolia* (L.) | vascular cryptogams | + |
| 19 | *Drosera rotundifolia* (L.) | vascular cryptogams | + |
| 20 | *Viburnum opulus* (L.) | shrubs | + |
| 21 | *Spiraea chamaedryfolia* (L.) | shrubs | + |

**Table 3.** Nutrient content and caloric power of components from peat and dead wood branches.

| **Type of sample** | **C (%)** | **O (%)** | **N (%)** | **H (%)** | **Heat (kJ/kg)** |
|---|---|---|---|---|---|
| Peat | | | | | |
| Organic matter + wood branches | 46 ± 8 | 30 ± 2 | 1.58 ± 0.1 | 3.96 ± 08 | 14,350 |
| Only organic matter, present in peat | 34 ± 11 | 33 ± 4 | 1.89 ± 0.3 | 4.36 ± 03 | 12,425 |
| Only branches of trees and shrubs, present in peat | 58 ± 16 | 25 ± 7 | 0.28 ± 09 | 2.99 ± 05 | 23,345 |
| Dead branches in the current layer of trees | | | | | |
| *Alnus incana* wood | 51.4 ± 3 | 28 ± 9 | 2.18 ± 0.3 | 4.96 ± 08 | 19,958 |
| *Betula humilis* wood | 49.8 ± 6 | 27 ± 5 | 1.24 ± 0.9 | 4.75 ± 04 | 18,995 |
| *Picea excelsa* wood | 50.3 ± 2 | 29 ± 7 | 1.35 ± 0.7 | 4.86 ± 07 | 22,648 |
| *Pinus sylvestris* wood | 50.9 ± 8 | 29 ± 8 | 1.32 ± 0.6 | 4.79 ± 05 | 22,996 |
| Dead branches in the current layer of shrubs | | | | | |
| *Viburnum opulus* wood | 49.5 ± 9 | 26 ± 9 | 1.98 ± 0.1 | 4.66 ± 05 | 17,858 |
| *Spiraea chamaedryfolia* wood | 49.9 ± 7 | 28 ± 2 | 1.38 ± 0.6 | 4.69 ± 04 | 18,158 |

An increase in carbon content is observed starting from peat towards anthracite, respectively graphite (Figure 1). Graphite together with diamond represents the fossilized biomass with the highest carbon content, reaching almost 100% in diamond. Due to the extremely low reserves of graphite and diamond in which the structure is no longer amorphous but crystalline (hexagonal for graphite and cubic for diamond), these two minerals are not used as a source of energy, having completely different industrial applications (Măldărescu, 1987).

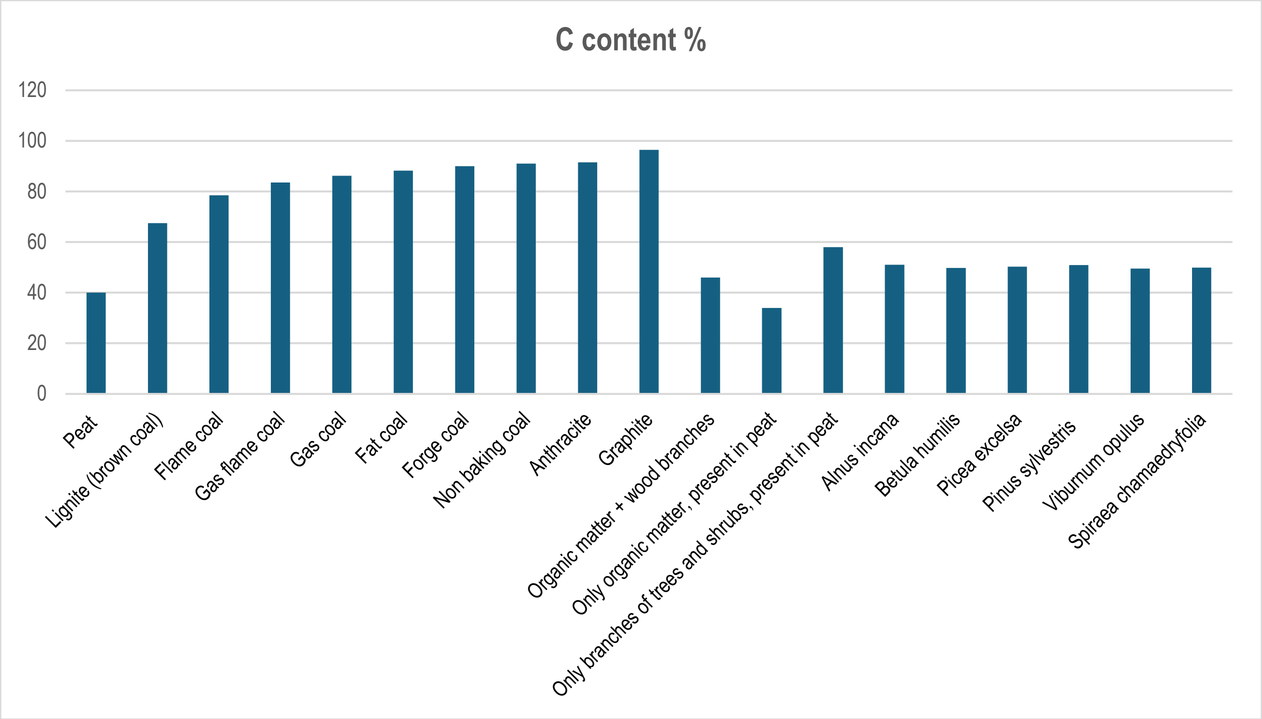


**Figure 1.** Percentage of carbon contained in coals and dead wood.

The carbon content is lower in peat, where it does not exceed 40% on average, compared to that in dead wood that has not undergone the fossilization process, which can exceed 50% in the case of oak. For this reason, some geologists such as Wagner consider peat a precursor to coal and classify it not as a fossil fuel but as an accumulation of dead organic matter.

Wood fragments in the peat layer that have undergone an early process of fossilization have a higher carbon content than dead wood that has not undergone fossilization (Figure 1).

This high carbon content in wood as a biomass recommends it as the closest renewable fuel to fossil fuels, namely coal.

Hydrogen has a low content in the composition of coals (starting from 5-6% in peat and lignite up to 2.5% in anthracite) and wood (4-5%), its content decreases slowly in the fossilization process starting from peat towards anthracite, and in wood it remains relatively constant regardless of the tree species.

The oxygen content is significant both in peat and in wood, it can reach 50% of the carbon content, the O/C ratio being close to 1 (Figures 2 and 3).

In coals, during the fossilization process, the carbon content increases at the expense of the oxygen and hydrogen contents that decrease. In wood, the oxygen content is relatively constant regardless of the wood species, it represents approximately 25% of the carbon content (Figures 2 and 3). Comparing the carbon and oxygen content between the nine types of coals analyzed, it is observed that in recent coals (peat, lignite) and coals with a higher metamorphic grade (anthracite, graphite) the carbon ratio decreases from 0.378 in the case of lignite to 0.016 in the case of graphite (Figure 3).

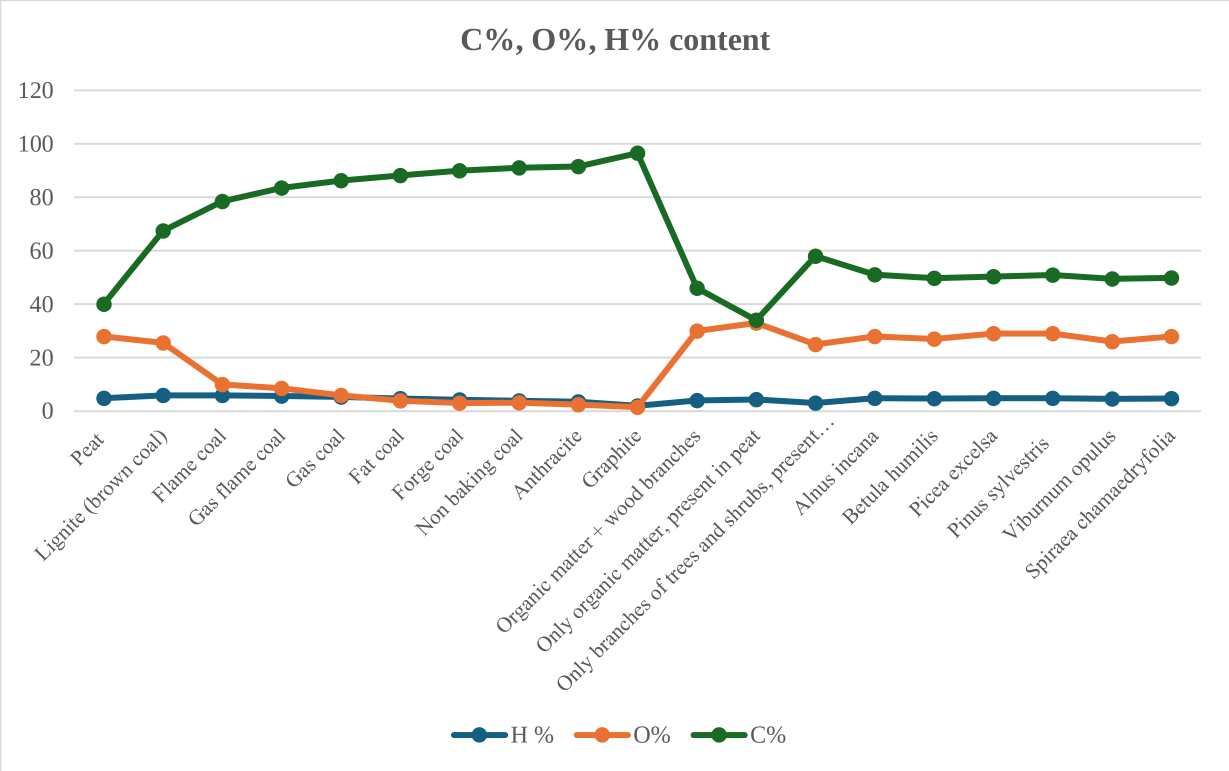


**Figure 2.** Percentage of carbon, hydrogen and oxygen contained in coals and dead wood.

We can say that the fossilization process is a process of enriching an organic matrix in carbon by releasing compounds rich in hydrogen and oxygen.

Oxygen leaves the system in the form of $NO_2$ through denitrification processes, and hydrogen by breaking the ends of various hydrocarbon chains forming $CH_4$.

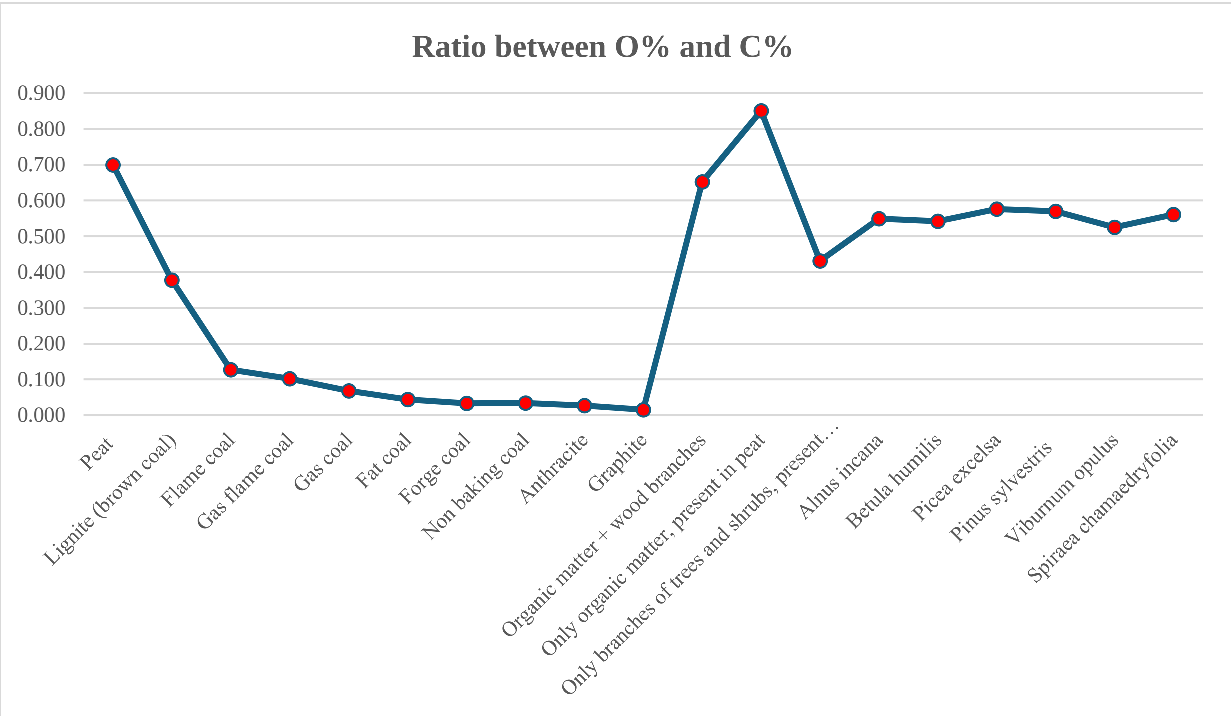


**Figure 3.** O% and C% ratio in coals and dead wood.

The calorific value of wood (between 18,995 Kj/kg and 22,996 Kj/kg) is higher than that of peat (14,350 Kj/kg) and closer to that of lignite (28,470 Kj/kg) (Tables 1 and 3).

Considering the fact that wood is the biomass with the highest carbon content and that most of the carbon resources were formed in the Carboniferous, woody bimass is a very important energy resource that can be easily transformed into products that they can be used as fuel in equipment that uses coal. Because the fossilization process occurs under conditions of anoxia, acidic pH, high humidity, high temperatures, and high pressures, it cannot be reproduced on a small temporary scale without a large expenditure of energy to reproduce these conditions. The process of fossilization of wood can be accelerated by storing it in conditions of high temperature, humidity and high pressure, knowing that after the depth of 20 m, the temperature in the boreholes increases by 1 degree C˚ for every 30 m lowered in depth, the thermal gradient being higher in areas with thermal waters. Considering that deep mining can reach up to 4000 m, the temperature in the mining galleries can exceed 134 C˚. In areas with thermal waters, this temperature can be far exceeded, and the presence of water in the aquifer that can flood the galleries would also create high humidity conditions. Thus, the galleries of mines that are no longer in operation can be used to store logs whose wood can accommodate a fossilization process. The storage would have a double advantage; the wood in a relatively short interval would begin to approach in terms of carbon content with lower coals (lignite), and for the galleries there would no longer be the risk of collapses. Since the carbon content of the wood present in the peaty matrix is significantly higher than the carbon content of the dead wood of the six woody species, one way to enrich the wood biomass in carbon is to bury dead tree trunks in the existing peat layers.

## 4. Conclusion

Wood is an important energy resource, its carbon content being in most cases higher than that of peat. This, under favorable conditions for the fossilization process, can be enriched in carbon, its properties becoming similar to lignite or other brown coals. This similarity with brown coals will allow the carbon-enriched wood to be processed in equipment similar to coal processing. Thus, there will be no need to implement new technologies, but only to upgrade the existing ones. Carbon-enriched wood represents an alternative solution to brown coals, which are exhaustible resources. Wood is the reservoir in which, through the processes of photosynthesis, carbon from atmospheric $CO_2$ is fixed and stored, so its production reduces the amount of atmospheric $CO_2$, a greenhouse gas that induces climate change. Carbon enrichment of wood could be achieved either by storing the trees in deep mining galleries, preferably in hydrothermal areas; or under layers of peat. The use of wood enriched in carbon, as an energy source, would solve two major problems of the use of brown coal: *i)* wood is a renewable resource, unlike coal, which is exhaustible; *ii)* wood production counteracts the effects of climate change by reducing atmospheric $CO_2$ concentration. The use of carbon-enriched wood as an energy resource is more advantageous than that of peat because worldwide peat resources are inferior to forest resources, and the calorific capacity of peat is inferior to wood.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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