

Article

# Greening the Brownfields of Thermal Power Plants in Rural Areas, an Example from Romania, Set in the Context of Developments in the Industrialized Country of Germany

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**Abstract:** This paper describes the greening of ash dumps from two thermal power plants located in Romania, in the villages of Mintia and Doicești, two rural areas neighboring middle-sized cities, both with architectural, archaeological and landscape heritage. Currently, the two Romanian villages have different fates in the context of shrinking cities, and solutions from the industrialized country of Germany that are more advanced in closing polluting thermal power plants are examples of this. Thus, the greening of industrial waste is one of the current challenges of the energy shift towards renewable energy. Nature-based solutions such as the proposed use of the biodegradable geo-textile in the greening is one of the current trends. The development of the biodegradable geo-textile was contemporary with the creation of the International Building Exhibition (Internationale Bauausstellung—IBA) Emscher Park in the ancient industrial coal mining Ruhr area, in Germany; later research, around 10 years ago, explored soil pollution at these two Romanian thermal power plants. A recent research study investigated the conversion of the industrial buildings of the thermal power plant in Doicești, however, these buildings were demolished at the end of last year. Mintia thermal power plant continues to function. This paper explores the current challenges of industrial brownfields, energy shift, ecology, the 21st yearly session of the Conference of the Parties (COP21) in Paris and “Laudato si”, spanning 30 years of history and the legacy of the research over this time.

**Keywords:** thermal power plants; coal-fired plants; geo-composite; energy; environmental pollution

## 1. Introduction

One of the uses of geo-textiles is to reinforce and stabilize steep slopes, for example, in the vicinity of transportation routes. The authors of this article observed such use in southern France. One example is in the United Nations Educational, Scientific and Cultural Organization (UNESCO) geo-heritage of Chaîne des Puys [1], where the final conference of the European Cooperation in Science and Technology (COST) action TU1401 “Renewable energy and landscape quality” [2] took place. This paper presents the safety measures and nature-based solutions for a different kind of slope stabilization: that of the ash dumps of thermal power plants, a fossil type of energy use, intended to be replaced by the above-mentioned renewable ones. The solution itself has gained attention in the last decade. Since the experiments were carried out to reduce the environmental impact of thermal power plants, the shift in energy transformed many such places into brownfields, and nature-based solutions for a blue-green infrastructure are considered suitable. Thermal power plants based on coal extraction [3] were the most important sources of energy, next to hydropower (see about environmental concerns [4]) in the production of energy in the socialism times. A later study of greening solutions from the 1990s was conducted in the first decade of the millennium [5] and dealt with soil degradation from fly ash. Then, in a third decade, Pleșea [6,7] proposed an architectural solution of conversion of the industrial

thermal power plant landmark in one of the two Romanian locations described in the previous two studies. Architectural integration of the two locations is possible, as there are archeological remains in both places (for example, the remains of the courtyard of the voivod [8,9]) and landscape heritage as well as Modernist architecture close to Mintia, in both the rural setting itself and the neighboring small province towns.

A review dealing with the energy shift and its consequences in Romania is given by the examples and studies of the first author in the industrialized country of Germany. There, already in the 1990s, when the first studies in Romania were completed, a building exhibition started to deal with the structural change after more unsuccessful decades in the International Building Exhibition (Internationale Bauaustellung—IBA) Emscher Park [10,11] in the Ruhr area. The lifetime of the mountain industry there was a little over 150 years, as in Romania, where there were also German settlers, providing the connection between the investigated areas. The new exemplary high-tech buildings employed renewable energy (e.g., Future Center Herten by Kramm ET Strigl with photovoltaic) among converted industry buildings, some of them UNESCO heritage, in a park. Although scarce, such conversion examples can also be found in Romania, for the waterworks in Suceava. The legacy of the IBA Emscher Park in light of the 20 years that passed since this conversion was re-examined in Jeng [12]. Therefore, it is our intention to re-examine the legacy of the developed geo-composite employed for greening brownfields in the current situation of the energy shift and shutting down thermo power plants 20 years later.

After the climate summit in Kyoto in 1997, between the 30th of November and the 12th of December, the United Nations Framework Convention on Climate Change took place in Paris as the 21st Conference of Parties (COP21), as the 11th meeting of the parties to the 1997 Kyoto Protocol. This was preceded by reactions from world leaders, such as Pope Francis encyclical “*Laudato si*” [13]. Pope Francis’ encyclical “*Laudato si*” addresses pollution and climate change, as well as technology, showing both creativity and power, and cultural ecology, which are issues addressed in the discussion of this paper. The encyclical argues for the closure of the polluting coal industry, and also for participative urban planning, as we will see at IBA Emscher Park. Under the Paris goals, coal power plants have to close in the foreseeable future [14].

The paper deals with post-industrial landscapes of coal mining to be converted through nature-based solutions. Several researchers have dealt with this topic. For example, Feng et al. [15] dealt with coal mining brownfields transformed into green infrastructure in China. In Zhang et al. [16], the topic was extended to industrial brownfields, also transformed into green infrastructure. Urban brownfields, in connection to the burning topic of circular economy, are also present in the work of Chowdhury et al. [17]. In Romania, thermal power plants also pose a technological risk [18].

There are not many papers proposing this solution, but the recent paper by Gajic et al. [19] examines a similar approach in Serbia, specifically the greening of fly ash depositions after the closure of mine activity. In this context, it can be seen how the legacy of the developed geo-composite can be applied in this new energetic context. In Song et al. [20], a method to quantify the benefits of brownfield greening was proposed. The broader problem of nature-based solutions applied for greening urban brownfields is approached in Zhong et al. [21], while in Hou et al. [22], coal mining and the green infrastructure networks today are explored.

On the other hand, while coal mining is the basis of the work of the thermal power plants with which this paper deals, the greening applies to the ash dumps resulting from the process. Assi et al. [23] investigate the problem for a north Italian town. Another north Italian town looked at from the point of view of brownfield greening is Trento [24].

This paper shows the materials approach to greening fly ash dumps by employing a biodegradable geo-textile developed by the second author. The fly ash results as a residuum of two thermal power plants placed in rural areas in Romania. Fly ash has also been, however, used for treating soil, as Lu et al. [25] and Ou et al. [26] show. In addition, the geo-textile employed in these studies is placed directly on the ash, with-

out a soil layer, and the layer is created through the decay of the geo-textile. Although Prambauera et al. [27] and Marczak et al. [28] give comprehensive reviews of the use of biodegradable geo-textiles for environmental applications, the use of greening ash dumps as in this paper is not covered. Instead, Wu et al. [29] cover the use of biodegradable geo-textiles in geotechnical engineering, while Shirazi et al. [30] look into soil reinforcement with precisely biodegradable geo-textiles, and Tauro et al. [31] look at soil loss reduction with biodegradable geo-textiles. Finally, Li et al. [32] look specifically at fly-ash–soil mixture. These results also reveal the novelty of the paper. For other uses, fly ash from these thermal power plants may not be suitable [33], and given these characteristics, landscape aesthetic regeneration is also proposed in this study, and not for agriculture. This must be seen in connection with the soil studies in Preda [5] about contamination.

## 2. Review of Approaches to Coal-Related Energy Shift Generated Brownfields

A seminal work by Loures [34] dealt with the potential of post-industrial landscapes in urban areas. The paper identified numerous such sites to establish the research. The same author's reviews focused on Portugal, in which greening of derelict sites is not enough [35].

In the following paragraphs, we review several approaches related to our research on present-day coal-related industrial sites and their fates. The situation is reviewed in two countries, Germany and Romania. In Germany, the structural change already started more than 30 years ago, when the biodegradable geo-textile was first developed and applied, and even 20 years later, the thermal power plants were still functioning, and under discussion concerning their pros and cons. Today, European and global policies lead to a global change related to such power plants, and the measures implemented in the Ruhr area by a pilot international building exhibition can be a model for the shift in Romania as well. A related study is the one on another post-communist country, the Czech Republic, in Duží and Jakubínský [36]. Another post-communist example is given by the closure of mining in Kuzbass [37]. The German example is considered, having the world's largest coal mines, and also because it was examined previously by the first author who resided there. The study presented in Chapman et al. [38] looked into the topic of how the shift in energy can be tied together with social equity. The early example of IBA Emscher Park has shown public participation included in brownfield redevelopment of former coal mining, and this shall be followed in the subsequent energy shift.

What constitutes success in brownfield redevelopment was presented in Silverthorne [39], among other research findings, in a framework of communicating results related to brownfields led by the Wessex Institute of Technology. The topic of greening brownfields was also approached here [39,40].

### 2.1. Industrial Heritage

#### 2.1.1. IBA Emscher Park—Coal Power Industrial Heritage

Structural change already started in Western Germany before 1990. After about 150 years of industry development in the mountain, workplaces were lost in the Ruhr area, and, because of potential high environmental costs, no new workplaces were created in other fields. Already in 1957, the precursor of the modern windmills were tested in the Schwäbische Alb area in Germany, but the focus was still on fossil fuels, and in 1972, the first thermal power plant in Neurath in Nordrhein-Westfalen (the Ruhr area) started to produce electricity. A change occurred in 1976 when Amory Lovins proposed, in the US, the soft energy as an alternative to nuclear and fossil energy and, as such, in 1977, Germany started to increase the production amount of renewable energy under the term “energy shift”, with photovoltaics in 1983, and since 1991, renewable energies are included in energy distribution networks in an obligatory manner, as shown in References [41,42] in connection to the recognition of the evidence of climate change. The Ruhr area was of high density. Between 1990 (starting in 1988 after 25 years of unsuccessful tries to revive the region) and 2000, the International Building Exhibition (IBA) Emscher Park “Workshop for the future of old industrial zones” took place, to requalify the former mining site of

the Ruhr area for modern technologies. The goal was a park across more communes of the Emscher Park, with the Emscher being the requalified river serving the older mining areas. With no pressure from investment, the project was intended as a new concept of culture, housing and work in a park from Duisburg to Dortmund. It meant ecological, economical and social restructuration. The term Park in the project's name represents "ecology". It was the first exhibition at this scale, for a whole region. The international building exhibition was organized around the following main projects (which included 120 individual projects):

1. Emscher landscape park, including thematic parks. Such a thematic park connected to the topic of this article was the ash dump event Emscherblick (Emscher look) in Bottrop (with the tethraeder). There are 46 ash dumps in the Ruhr Area, many of them converted into land art works [43]. At the final of the IBA in Palace Oberhausen, an information event took place on "Art sets signs", presenting how dumps and other industrial buildings (towers, gasometers, etc.), became artistical shapes. Blue-green infrastructure was already followed in this early project according to the thesis for the free space, which will become the infrastructure of the future. Green corridors from A to F were made, as well as an east–west corridor. One hundred years ago, in the 1920s, Robert Schmidt had already seen the coming crisis, but it was not yet time for his ideas.
2. The reconfiguration of the water system of the Emscher River.
3. The experience space Rhine-Herne channel.
4. Industry monuments as bearers of culture, such as, for example, the Zeche Zollverein.
5. "Working in the park" (22 sites), in the brownfields of mountain industry. This was intended to create workplaces. Following types were followed: cross-region science parks with high state investment, industry parks for new neighborhoods, founder centers for small enterprises, revitalization of industrial zones. The new centers had to radiate new developments in the areas. An example of creating new places was "Die Fraueninitiative zur Entwicklung dauerhafter Arbeitsplätze" FRIDA (women's initiative for developing permanent working places) in Oberhausen. Seventeen technology centers were created.
6. New housing (3000 new dwellings) and modernization (another 3000 according to monument status for garden cities of the workers) of housing (26 projects), through competitions, with participative planning (e.g., Women plan, build, dwell in Bergkamen).
7. New offers for social and cultural activities, which also included art on the dumps. It included social initiatives, employment and qualification. This way, long time unemployed personnel could be helped.
8. Since 1993: integrated neighborhood development.

The strategy which made the initiative successful was that the top-down initiatives at land level were coupled with local initiatives. But most important was that it was in the direction of the planning philosophy of the 1980's strategy, which meant action plans and program goals followed according to this. From a planning theory point of view, incrementalism was followed. The lead projects were thought to spread in the area as good examples, and as a consequence, other projects would be initiated. The actions proposed in the urban strategy (more specifically in the action plan) were thought of as learning processes for the local actors. The instruments employed in the strategy included: a lead plan for implementing the strategy, the partial framing plans (urban regional plans as well as a landscape regional plan), and project promoters for the steps proposed to implement the strategy.

The first author of this paper wrote about the IBA Emscher Park being the superposition of all four participative planning layers since the 1960s in their two generations, from participation to communication [11]. This conveyed hope that the structural change and the reuse of brownfields from the former coal industry can be done by participative means. The support of the inhabitants was important, as they had already resigned to not believing in the future.

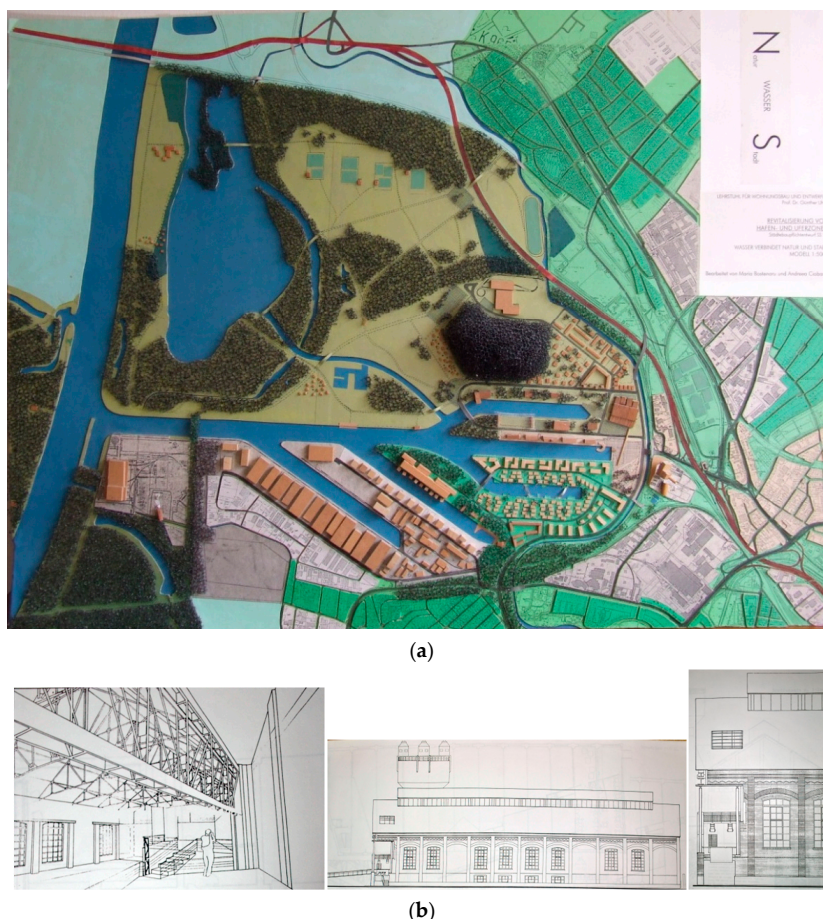


The result was four specific routes to explore: industry culture, industry nature (including the brownfields and ash dumps as signs of industrial landscape shapes), land making art and architecture (the projects). In the land making art, the postindustrial landscape was ecologically-economically reshaped.

During the years following the exhibition, some of the industrial heritage items were classified as World Heritage, such as Zeche Zollverein. Zollverein was once one of the biggest energy conversion machines of the world. At the closure of the IBA exhibition, the history of energy (sun, moon and stars) from the point of view of culture as well as natural science took place.

### 2.1.2. Other Urban Dimensions of Industrial Heritage in Germany

In 1998, the first author of this paper worked on an urban planning student project for the Rhine port in Karlsruhe, Germany (Figure 1). It was not the only project, since another one was also done for the Rhine port in Mannheim, for the conversion of an industrial building as proposed for Karlsruhe but following intervention principles as recommended by Carlo Scarpa for industrial buildings in Italy.



**Figure 1.** (a) Project for the greening of the Rhine harbor in Karlsruhe, including the thermal power plant. Project by Bostenaru Dan and Ciobanu, 1997. (b) Conversion project for a warehouse in the Rhine harbor of Mannheim up from Karlsruhe.

The motto of the solution was N-S, north and south, nature and Stadt (city). The Rhine port is situated in the vicinity of the systematized Rhine, which was cut from the old branches in the old school of flood protection. These remaining old branches are natural valuable areas. The solution proposed condensing the warehouse area for culture and housing, replacing it and greening of the landfill present in the port. A related topic, the incineration municipal solid waste (MSW) ash, is the subject of Lam et al. [44].

Landfill greening with geo-textiles was also proposed, since it was already performed in Romania [45]. At the entrance, the port of Karlsruhe features a thermal power plant. No intervention was proposed on this, but, considering that Germany will be leaving coal fuel for energy by 2038 [28] following COP21 Paris and the thermal power plant will be shut down, this could be integrated in a natural solution, such as the one proposed in this paper. Coal for the thermal power plant in Karlsruhe comes over the Rhine from Nordrhein-Westfalen, the Ruhr area, similar to what is described in this paper, based on the situation in the Romanian site of Jiul Valley.

The design project for the conversion of a warehouse in the Rhine port of Mannheim, up from Karlsruhe, can serve as a model for the warehouses proposed to be converted in the Rhine port of Karlsruhe, keeping them as heritage buildings, while deposit areas of less value are compacted so that the place becomes free for housing and nature.

Other study works are the following. A building survey concerning the textile factory in Myslakowice, now Poland (at the time of building this factory, it was Germany)—this factory functioned till the 2010s, and finally, the diploma work of the first author of this paper, concerning the design of a museum of water in the Maine East port in Frankfurt in the neighborhood redevelopment designed by David Chipperfield. The industrial area of a port is thus a new approach.

#### 2.1.3. Protection Issues

TICCIH (The International Committee for the Conservation of the Industrial Heritage) is an international organization for protection of industrial monuments and industrial archaeology, founded in 1973. In 2003, a Charter was adopted. The guidelines also include coal mines, which, among others, contribute to advising the ICOMOS (International Council of Monuments and Sites, an intergovernmental organization). Watercraft, another form of energy, also promoted in Romania during the socialism time, and maintained as renewable energy, is also included in the guidelines.

#### 2.1.4. Industrial Heritage in Romania, an Example of Successful Conversion

Greening of industrial sites as proposed in this paper is not singular, not even in Romania. In 2012, 100 years after it was built (at the time of the Austro-Hungarian Empire), the converted so-called “Water plant” (Figure 2) of Suceava was opened to the public as a cultural center. The interior is buried, and the cover was greened. The intervention was examined in an article related to sociology [46], just at the moment it was launched.



**Figure 2.** Restoration and greening of the former waterworks in Suceava, Romania. Also, a geo-composite can be observed. Photo: M. Bostenaru, 2012.

## 2.2. The Shift in Energy

Evaluating the consequences of technique and industrialization led to the shift in energy from using fossil fuels to renewable energy. COST Action TU1401 “Renewable energy and landscape quality” (COST RELY [2]) investigated how nature and renewable energy can be reconciled, since blue-green infrastructure and nature-based solutions also respond to the climate change response strategies foreseen by COP21.

Leaving nuclear power already led dedicated university chairs to the demolition of the nuclear power, such as the Karlsruhe Institute of Technology, Institute for Technology and Management in Construction in Germany. But Germany is also engaged to close all coal thermal power plants by 2038, following the Paris 2015 climate summit. An overview on how long takes to close a coal thermal power plant is given in Reference [47], with Vögele et al. [48] examining the phasing out of coal-fired plants in Germany.

In Romania of the socialism time, planned economy made it possible to perform large-scale industrial installations, such as large hydro-power and large thermal power plants. Starting in January 2021, in Romania, there is also a free energy market, so users are able to choose which source to use for electricity.

The National Technical Museum in Bucharest “Dimitrie Leonida”, administrated by Electroworks, founded in 1909 by Dimitrie Leonida after the model of the Deutsche Museum in Munich, houses various items related to electricity and energy. As such, original pieces from thermal power plants, as well as small-scale models of these plants, are included. Unfortunately, no models are available for the Mintia and Doicești thermal power plants, which are the subject of this paper.

Estimating the consequences of technique is a topic for a course on Applied Cultural Science at the Karlsruhe Institute of Technology (KIT), as technology is part of our culture, thus enhancing the importance of industrial heritage, a contribution of the Institute for Technology Assessment and Systems Analysis of the KIT [49]. The institute also discusses the “Sustainability and transformation of the energy system” [50] among its topics. Among others, it coordinates cultural change for achieving this sustainability. The current number of lookKIT, the magazine of the Karlsruhe Institute of Technology, is dedicated to “The energy system 2050” [41]. It includes an article on the energy shift, including an overview of the history of production of energy from coal mining and thermal power plants to the return of windmills, as introduced in Section 2.1, when describing the structural change in the Ruhr area. The German solution is the so-called “Energy system 2050” [41], which gives a guideline on how an industrialized land can achieve neutrality.

## 2.3. Introduction of the Romanian Research Case Studies in This Paper

Coal fly ashes accumulations in Romania in the 1990s reached about “1830 ha ... leading to the elimination of large areas from agriculture and contributing to landscape degradation” [51]. The dust generated by these ashes is contributing to air pollution and through it to soil and plant pollution in the vicinity of the ash dumps. The study of Preda [5] examined such soil pollution for the two sites included in the research case studies of this paper.

Romania is also required to slowly close down the thermal power plants in order to comply with the European standards in terms of environmental pollution, starting 2021 [52].

The use of a biodegradable geo-composite was examined to see if the ash dumps can be covered to prevent environmental pollution. A biodegradable geo-composite is from natural fibers (textile) which decays in time and supports the roots of the growing plants to assure the stability of the new landscape. Gramineous plants and vegetable seeds were used for the greening, in both single and mixed crop. The first phase was laboratory research to establish the best plant species to be used in situ. The two thermal power plants chosen for the studies were the ones in Mintia-Deva and in Doicești by Târgoviște. The same geo-composite can also be used for slope reinforcement. The biodegradable geo-composite enriches the soil on the ash dump with bacteria, mushrooms and other

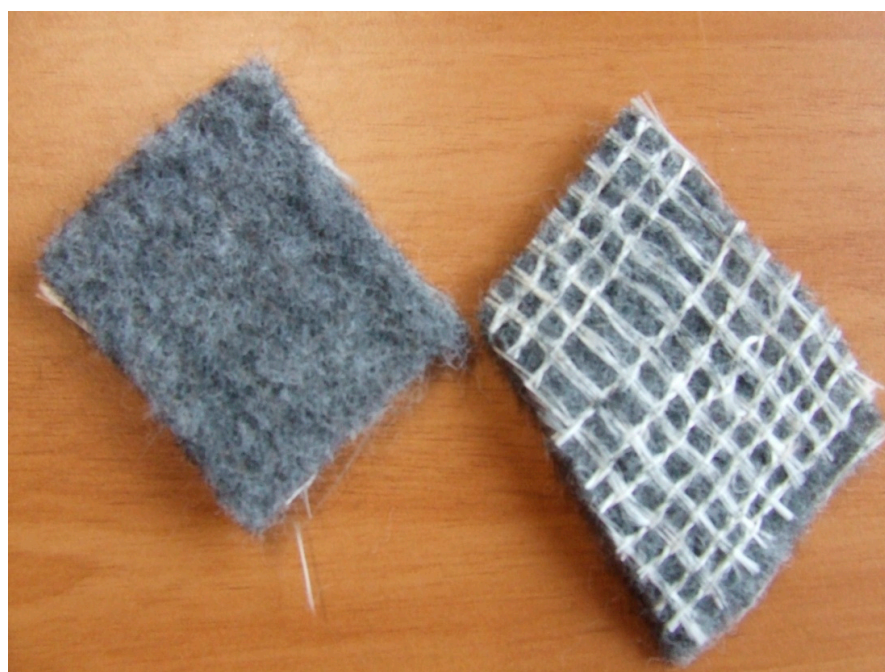


biological activity and microorganisms, and it can be used similarly on waste dumps. The aim was not the agricultural crop, but to reverse landscape degradation and create an industrial landscape, as seen in the German case studies.

### 3. Materials and Methods

#### 3.1. Materials

The geo-textile is a geo-composite (geo-textile on support layer) produced by a textile manufacturing technology, either by carding or winding. In the carding technique, a fiber mat of variable thickness is produced (Figure 3, Table 1). The fiber mat is fixed on a support by the interweaving technique using a special equipment of plates, needles and groves, and is thus reinforced. The needles,  $15 \times 18 \times 32 \times 31/2''$ , are punching the fibers,  $50\text{--}100/\text{m}^2$ , into a felt. The felting process causes random directions of the fibers, including voids in between. The fiber mat is placed on the top, and the support, created through the interweaving technique, is placed on the bottom. In these voids, it is possible for the roots of the plants to insert after seeding. Since the geo-composite is biodegradable, the fibers are natural, such as cellulose, wool (both recycled) and similar ones. The thickness of 2–5 mm of the geo-composite provides an adequate support for plant growth in the initial vegetation stage. To compare, green walls could be looked at, where only the textile support with water and vitamins ensures growth conditions [53,54].



**Figure 3.** Geo-composite material. Photo: M. Bostenaru, 2006.

**Table 1.** Characteristics of the geo-composite. After Siminea and Bostenaru [51].

Characteristics	U:M	Value
Total weight	$\text{g}/\text{m}^2$	$300 \pm 10\%$
Wet weight	$\text{g}/\text{m}^2$	$2000 \pm 200$
Initial thickness	mm	$3.5 \pm 1$
Wet thickness	mm	$3 \pm 1$
Initial porosity	%	$93 \pm 5$
Water saturation capacity	%	$40\% \pm 5\%$
Saturation capacity	%	$200\% \pm 100$
Air permeability	$\text{L}/\text{m}^2\text{s}$	$1000 \pm 10\%$
Resistance to micro-organisms' action		medium behavior



The choice of plants to be seeded included perennial herbs, cereals and vegetable crops, in accordance with the climate of the given geographical area of the thermal power plants. The characteristics of soil were also considered. The choice of plants was as follows [51], as they are recommended for use on alkaline ground fly ashes:

- Cereal crops: dented sedge, tick sedge, creeping sedge, non-aerated brome grass.
- Vegetable crops: white melilot, bird's foot trefoil, creeping white trefoil.

For slopes, other plants are also recommended. From the plants used here, lucerne and turf grass (which were determined in the laboratory testing) are recommended on salt ground. Lucerne is also recommended on sand and on slopes.

### 3.2. Methods

Fly ashes are thermal power plant waste, consisting of fine crushed coal, burning in the air. In large amounts, they are disposed in waste dumps. Because it easily causes environmental pollution through air and soil spread, fixing the particles is a first step in environmental protection from thermal power plant pollution. This fixing can be done through [51] spray watering on fresh dumps, chemical fixing by emulsions and biological fixing by vegetation. The biological fixing includes a 10–20 cm thick earth cover, mud cover, peat, or a mixture of 10 cm of earth and ashes. Using a biodegradable geo-composite instead of thick earth showed more advantages for grassing and ash fly scattering prevention [55,56].

#### Laboratory Testing

In laboratory testing, the biodegradable geo-composite was applied on the thermal power plant fly ashes in vegetation pots over 6 months. The aims of the testing were [51]:

- Testing the perennial plant varieties which can grow in the given conditions.
- Testing the ash dump (from Doicești and Mintia, see Tables 2 and 3) capacity to sustain plant growth.
- Determining how the geo-composite decays and integrates in the soil.

**Table 2.** Physical and hydro-physical characteristics. After Siminea and Bostenaru [51].

Thermal Power Plant	Oxide Compounds, %									PC	Salts
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	FeO <sub>3</sub>	CaO	MfO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>		
Mintia	50.9	36.5	10.7	5.9	2.1	0.9	0.9	1.9	1.21	1.59	0.0809
Doicești	48	23	8.1	9.2	3.0	3.7	0.4	1.7	1.58	3.11	0.0419

**Table 3.** Physical and hydro-physical characteristics. After Siminea and Bostenaru [51].

Thermal Power Plant	Grain Size Composition %					Density g/cm <sup>3</sup>	Hygroscopy Coefficient
	2–0.2 mm	0.2–0.02 mm	0.02–0.01 mm	0.01–0.002 mm	<0.002 mm		
Mintia	7.8–9.1	0.55–0.85	2.8	12.3–16.8	9.8–14.2	0.55–0.85	2.8
Doicești	8.2–11.5	0.63–0.87	6.7	7.1–9.9	3.7–5.2	0.63–0.87	6.7

A complex nitrogen (N), phosphorous (P) and potassium (K) fertilizer was used. Wetting was provided every two days.

## 4. Results

### 4.1. Site Location

Both thermal power plants investigated are situated in hilly areas, but in different parts of the country. Both thermal power plants are situated in rural areas next to medium-sized cities. Mintia is a village in the commune of Vetel, while Doicești is a commune with several villages.

#### 4.1.1. Mintia

The thermal power plant has worked since 1969, having branches installed until 1980. The thermal power plant is situated 9 km from the city of Deva and managed by Electro-works Deva.

The city of Deva discovered a touristic vocation in the recent past, given by its vicinity to the Dacian fortresses (UNESCO heritage), the Corvinus Castle in Hunedoara, the Arboretum in Simeria and the recent Italian gardens in Banpotoc. Mintia itself has archaeological heritage and also other monuments from the time of German and Hungarian settlements. To fully take advantage of the touristic heritage, a reduction of environmental pollution is necessary.

Mintia is close to Jiul River Valley, the main mining site of Romania [57]. On the other hand, King Ferdinand of Romania considered Jiul River Valley the most beautiful landscape in Romania.

According to Preda [5], the Mintia thermal power plant has an important role in the energy system because of its geographical balanced position and its main connection with the electrical energy transport in the European Union. By 2011, it used 90% of the bituminous coal production from Jiul River Valley. One of the mining sites is Petrila, a locality with a shrinking population, as presented in recent studies [58]. Constantinescu's doctoral thesis discussed this topic, and she later published a book [59] accompanied by an exhibition (the book is like a catalogue of the exhibition). Jiul River Valley played a central role in it. The shrinking cities in Jiul River Valley were also the subject of the film "Planeta Petrila" (Planet Petrila) [60]. The film shows the extraction of the last ton of coal from the mine, which was the oldest (156 years of functioning) and deepest in the Jiul River Valley. After the closure of inefficient mines in the Jiul River Valley through a dedicated society, only four mines remained. The thermal power plant thus assures working places for these industrial sites.

Geographically, the area includes the valley of River Mureş and the vicinity of several mountainous chains. The Jiul River Valley is the largest coal production site in Romania. In its vicinity is the mountainous Banat area, an area of the Danube Swabian German settlers, and also the place of the mountain coal industry. The mountainous part of the Banat region was earlier closed and the coal industry was relocated to the Jiul River Valley and to Mintia [61]. Iamandescu [62] also wrote a case study on the mountainous part of the Banat region. Before the industrial archaeology in the mountainous Banat was the subject of a research project at the home university of the first author of this paper, Anina from the mountainous part of the Banat region also appeared in Constantinescu [58].

The ash is deposited in two dumps. According to Preda [5], the contents of these ashes are: 0.0–46.7% coarse sand, 24.4–82.6% fine sand, 1.2–66.4% dust and 1.0–11.0% clay < 0.002 mm. The heavy metal content was as follows: copper 49–477 ppm, zinc 50–1020 ppm, lead 22–1014 ppm, cobalt 20–30 ppm, nickel 74–310 ppm, manganese 212–2294 ppm and cadmium 1.1–4.2 ppm. Some chemical characteristics were: pH 8.25–9.50, total nitrogen 0.095–0.139%, mobile phosphorus 0.2–84 ppm, mobile potassium 65–285 ppm and cation exchange capacity 1.06–5.32 me/100 g. The humus varies but is polluted with carbon dust. Pollution varied in the investigated soils and had to do with the atmospheric spread of pollutants as well.

#### 4.1.2. Doiceşti

The thermal power plant in Doiceşti was the oldest in Romania (the old Section was from 1952 to 1956 and a new section from 1979) and a cornerstone of Romanian industrial architecture. A book on architecture from the communism time [63] included an archived photograph highlighting the aesthetics of the industrial architecture at that time. Tulbure [64] illustrates a picture from "Contimporanul" (a magazine from 2 January 1952) describing the achievements during the Stalinist time, and including the hydropower from Romania Bicaz and the thermal power plant of Doiceşti, along with the Press house.

The thermal power plant is situated close to Bucharest but even closer to the Carpathian Mountains, in a hilly region close to the city of Târgoviște, the former capital of Wallachia. Târgoviște is not only rich in architectural heritage of the past, but also Doicești itself preserves archeological remains of the Brâncoveanu court, which have been documented by the “Ion Mincu” University of Architecture and Urbanism in both glass slides with 100-year-old photographs [8] and in a building survey of the Brâncoveanu time church (1706) [9].

Because of pollution, the thermal power plant was shut down in 2009 and sold by Termoelectrica in 2014, after initiating its liquidation in 2013. Doicești had no juridical personality of Termoelectrica; Electrocentrale Deva, which includes Mintia, is one of 3 branches. In 2019, after a study [6], Pleșea [7] prepared a restoration plan and recommended keeping the architecturally valuable building of the thermal power plant with new functions related to the rural setting and its traditions, using as an example the Duisburg park in the Ruhr area (part of the IBA Emscher Park). In his doctorate thesis, Lakatos [65] wrote about examples outside Romania, regarding the conversion of industrial sites, and this problem was also approached at the launch of the mentioned cultural center in the water plant in Suceava, where the first author of this paper presented the urban dimension in Germany. However, in December 2020, the thermal power plant was demolished. The study of Pleșea [6] reported that after the closure of the thermal power plant, the village did not shrink, as the population found alternative working places in neighboring localities. The condition of the environmental pollution in the Dâmbovița County, where Doicești is located, is also examined in Sencovici [66].

Geographically, the location is on the Ialomița River and Dâmbovița River valleys.

Doicești was using lower quality coal (lignite) from the neighboring village of Șotânga.

The study on soil pollution [5] documents the pollution as follows: coal was not desulfurated, pH of soil was neutral and humus varied largely but was rather low, enriched by organic carbon shown by C/N report. The soils are light alkaline, and due to it, they resisted well to acid pollution. The pollution also includes heavy metals, Zn and Cu, where Zn also comes from other sources. In the immediate vicinity of the thermal power plant, the coal dust also causes pollution.

About 50% of the sites are in the meadow, on alluvial soils (AS) (most ASeu, and the rest is entic soils, pebbles, gleyed soils). The rest of the soils are: cambisoils—17.65% (typical eutricambo-soils, lithic and spolic soils), luvisols—17.65% (typical and reddish preluvo-soils, typical and stagnant luvo-soils), regosoils—8.82%, cernisoils—2.94% (rendzinecambic soils) and pelisoils—2.94% (typical eroded verto-soil) (SRTS, Florea and Munteanu, 2003, according to Preda [5]).

#### 4.2. Laboratory Research

Different results were obtained for fly ashes from Mintia (M) and respectively Doicești (D). Lucerne plant grew better at the Doicești fly ashes (Figure 4), while turf grew similarly in both locations (Figure 5).

The decay over time of the geo-textile is shown in Table 4 [51]. The table shows increased bacteria and hydrogenozic activity. The geo-textile exhibits a much higher activity than the ashes, and therefore is a better medium and will contribute to formation of soil on the waste dumps. Mechanical resistance of the biodegradable geo-textile was also determined according to textile engineering.





Figure 4. Lucerne. Photo: I. Siminea.

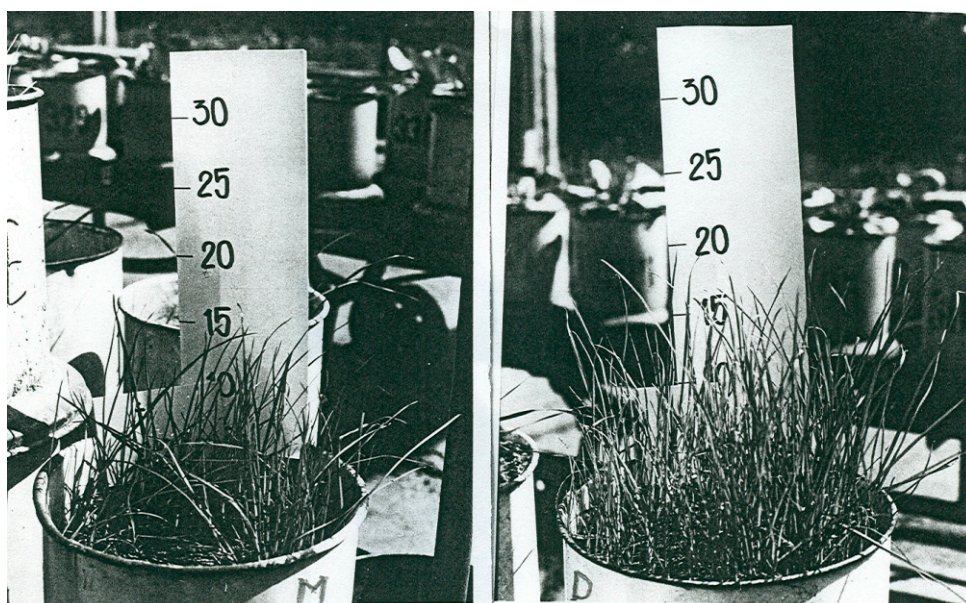


Figure 5. Turf grass. Photo: I. Siminea.



**Table 4.** Biological parameters of the ash and the geo-textile in the laboratory. After Siminea and Bostenaru [51].

Sample	No. of Bacteria million/g	No. of Fungi Thousands/g
Doicești ash	18.2	25.3
Mintia ash	13.5	19.6
Cultivated geo-textile	31.5	51.5

#### 4.3. In Situ Research

Following the laboratory results, in situ research was done. Figure 6 and Table 5 show good results at Doicești power plant. The same observations were obtained in situ as in the laboratory testing regarding the microbial activity in the geo-textile and the ashes. The geo-textile transforms into a natural fertilizer.

**Figure 6.** Turf grass and lucerne on the ash dump of the Doicești thermal power plant. Photo: I. Siminea.**Table 5.** Biological parameters of the ash and the geo-textile in the experimental field. After Siminea and Bostenaru [51].

Sample	No. of Bacteria million/g	No. Microscopic Fungi Thousands/g	Hydrogenozic Activity Formazan mg/100 g
Doicești ash	15.3–17.8	20.1–23.3	38.5–39.1
Geo-textile	25.6–26.8	41.3–42.8	58.6–61.3

## 5. Discussion

The energy shift reached Romania, although decades later than the Germany's structural change. The two thermal power plants discussed in this paper for nature-based solutions, namely greening of fly ash dumps, have, at the moment, different fates. One of them was closed, and the heritage buildings, although landmarks of industrial architecture in Romania, were demolished. The other is still in use, and this may be thanks to the vicinity of high-quality bituminous coal mining. Though, coal mining is on the way to being closed, there is an active society for the closure of mines in Jiul River Valley. Energy from coal plants needs to be replaced by renewable energy. In this context, research has been done as part of the COST action TU1401 COST RELY ("Renewable energy and landscape quality") [2]. Both types of research, the COST action research and the research presented in

this paper, focused on a landscape-related shift, building and protection of the blue-green infrastructure.

The laboratory research demonstrated that both cereal and vegetable crops proved suitable for ash dumps. The biodegradable geo-textile proved suitable for the protection of a decayed surface. The decay of the geo-textile already started in the 6 months of the laboratory testing. Watering is recommendable.

The in situ testing proved that the geo-textile immediately retained fine coal dust particles from spreading in the wind, long before plant growth. The biodegradable geo-textile was a proper mechanical support for plant root anchoring. The culture of the plants seeded was enriched by spontaneous flora which made roots on the geo-textile. The geo-textile kept good moisture after sprinkling. The decayed geo-textile became a natural fertilizer and created a good soil out of the fly ashes. Thus, it can replace the topsoil.

This review showed that approaches on greening brownfields are not singular. It took place in both urban and rural areas, including in post-communist countries, although in the example of Portugal it proved to be not enough [35]. Research on rural areas is not so extended. There is related research on greening of former coal mining sites, and in this context, this research on coal-fired plants may build a continuation. In this context, the link to research in Germany is worth noting. Structural change in energy and in abandoning the fossil fuel already started there decades ago (about 30 years ago), when the geo-composite applied in these case studies was designed, and the former coal mining regional area of the Ruhr zone was transformed in a cross-regional park, the Emscher Park, using the instrument of an international building exhibition. The industrial architecture landmarks were integrated, and so were the fly ash dumps, creating land art installations in the landscape. Germany continues to work towards the energy shift, and the COST RELY action was coordinated by Germany. This work discusses the effects of technology nowadays.

The fact that the industrial landmark of Doicești was not preserved is not singular in the industrial architecture of Romania. The coal mining sites in the Jiul River Valley, and also in the neighboring region of mountainous Banat, face the same challenge as the rest of the Romanian industrial archaeology, while Petrila displays a positive example thanks to citizens' engagement. There is a link between the developments in IBA Emscher Park and Planeta Petrila which shows how citizens got involved in post-industrial development. Having had a totalitarian regime, citizens' participation developed later in Romania, compared to Germany [11], as shown in the IBA Emscher Park. The first attempts were protests, mainly in the field of the ecologic turn, since low-rise housing and green areas were the most exposed to speculative action, and therefore destruction in order to make place for high-rise housing. The development was, however, fast, and accompanied by contemporary digital instruments. The example in Planeta Petrila is an example of constructive citizen participation, and not yet second generation. In Doicești, this did not succeed, although the study in Pleșea [6] gave the example of the Duisburg Park, part of IBA Emscher Park. This shows the need of the urban sociology and the sociology of the architecture approach to enforce architecture solutions. This is also needed for the energy shift, as shown in the review of Chapman et al. [38]. There are also other positive examples of industrial conversion in Romania, like the so-called "water plant" in Suceava, a former water station, situated underground. The analysis of the conversion presented in the literature is using the sociology of architecture point of view and it was published in the Romanian Sociology (SR) journal. The work also features employment of geo-textiles in greening the slope above the underground industrial tube, which hosts the new Centre for Architecture, Urban Culture and Landscape.

The biodegradable geo-textile, as Siminea and Bostenaru [51] shows, was also tested for sloped areas. This was not the subject of this paper, but it may be thus suitable for solutions like the one shown for the "water plant" in Suceava or for greening rubbish dumps, as shown in Lam et al. [44]. The study in Lam et al. [44] also shows work of the Romanian chapter of the International Geosynthetics Society; the second author of this

paper is one of the founding members of this society. Such greening of rubbish dumps was proposed in an urbanism project of the first author of this paper, for the port of Rhine, where the objective was to green the area and turn it into a bridge between city and nature. The port of Rhine also features a not yet closed thermal power plant. Since the closure of thermal power plants in Germany will also take place in the future, the solutions discussed for the Doicești and Mintia power plants may apply. This way, these solutions will spread, as was the aim with the IBA Emscher Park.

Finally, the solutions proposed in this paper are characterized by a high degree of novelty; as learned from the consulted literature, the most similar one is the approach in Serbia [19]. This is an approach to fly ash greening in a post-communist country as well.

In writing this paper, the authors also reviewed the use of geo-textiles and geo-composites in geotechnics, in order to fundament the solution. Bio-degradable geo-textiles are still seen as a solution of the future (green geo-textiles). As the cited papers show, the geo-textile reinforces the soil and shows a good combination with soil, and even with the fly ash, a fact also proven by the study in this paper. Further research will compare the solution with other green solutions, such as green walls which use non bio-degradable geo-textiles. Both solutions can be used to green urban and rural areas, for walls and roofs respectively, and thus contribute to green infrastructure.

Like in Jeng [12], this paper presents the legacy after more decades of research. Although, in time, the general conditions of the coal industry have been exposed to changes, the solution remains nevertheless viable, and more than ever in demand, due to the contemporary development of nature-based solutions.

## 6. Conclusions

This paper presented a proposed solution to build blue-green infrastructure, by discussing this solution in the greening of two thermal power plants from the rural hilly areas of Romania. The paper approaches the relationship between the energy shift and greening of brownfields in the post-industrial era, both being aspects of the ecological turn today. The two thermal power plants are Doicești and Mintia. The authors' proposal is to green the fly ash dumps. To achieve this goal, a biodegradable geo-composite was developed at the time structural change appeared in coal mining in Western Europe countries, such as Germany, and at the same time, Romania entered a post-communist era.

Vegetation growth was not uniform in Doicești and Mintia. This depended on the plants used as well as on the fly ash. The coal used in Doicești and Mintia has differences (lignite and bituminous coal, respectively). The geographic place also differs, which resulted in a different role of the thermal power plants in the energy economy of Romania. The plants dried in Mintia. In Doicești, the fly ash is more suitable for plant cultivation. However, the goal was not to provide agricultural crops, but to seed domestic plants in order to repair degraded soils and integrate industrial waste in the circuit.

Since the studies took place, the thermal power plant in Doicești was closed and demolished, probably also as a consequence of the differences in coal used and the position in the energy network. The dumps must now be integrated in the landscape, following the example of the IBA Emscher Park in Germany, or by creating a new industrial landscape, and enriching the zone with remains of the past, at least in the landscape, if the architectural landmark could not be preserved. The project on urban dimension of industrial architecture in Karlsruhe, Germany, can also be an outgoing point for a future project, where lessons are learned from the IBA Emscher Park, and from here, are integrated with the lessons from the Serbia project as well. This site also features a thermal power plant, which uses the coal from the Ruhr area over the Rhine and is connected with other industrial projects. In Mintia, the ash dumps, which are still growing because of continued functioning of the plant, need to reduce the environmental pollution, and as such, the research shall continue. In the future, however, all thermal power plants will be closed, and actions should be taken for keeping the industrial landmarks from demolition. In Mintia, the thermal power plant is facing problems these days, due to reduced quantities of coal. Examples of conversion of

industrial sites in Romania are sparse, but the so-called “water plant” in Suceava is a good example, and it is also an example of greening, due to the use of bio-degradable geo-textile. Similar examples as the ones used in this paper can be used, as well as in the Karlsruhe project. For this reason, papers on the use of geo-textiles, in general, and bio-degradable especially, were reviewed. In the cited literature, some international examples which can serve Romania were approached.

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