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THREE-DIMENSIONAL BROWNFIELDS: THE TRAGEDY OF THE MINING COMMUNITIES

Abstract

The processes of active restructuring in the mining industry of many countries have entailed the physical closure of enterprises, accompanied by measures to mitigate their environmental and social impacts. Brownfields that emerged in districts with developed mining industries are predominantly perceived through a stereotypically flat, superficial, and narrowly literal lens. Adhering to such an approach is risky both in terms of ecology and in the aspect of economic losses incurred in territories with concentrated localization of mines. The article provides substantiation for the importance of perceiving brownfields within a three-dimensional space, with due consideration given to geological deformations, dynamics of underground water and gas flows, and the potential of gravitational and geo-thermal energy. The authors propose interpreting brownfields as either oper-

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ating or abandoned industrial sites with buildings and infrastructure facilities on the ground surface, as well as natural landscapes that are negatively affected by geological, hydrodynamic, and gas-dynamic processes characteristic of the disturbance of the subsoil due to underground or open-pit mining operations. The reuse and recycling of industrial waste accumulated within brownfields alone cannot ensure the survival of coal-mining towns. Similarly, depopulation cannot be halted solely through economic instruments. Thus, the strategy for the development of coal-mining towns should entail 'enlightened' restructuring in line with the ideas of 'Smart Shrinking'.

Key Words:

coal-mining industry; coal-mining town; coal regions; environmental risks; Smart Shrinking; three-dimensional brownfields.

JEL: O18, O38, Q32, R11.

1 figure, 27 references.

Problem Statement and Literature Review

The French writer Michel Tournier is often credited with the statement: Geography was created by God, and history by the Devil. This dialectic can be exemplified by the opposition between greenfield sites or *green fields* – a term used to designate virgin, uncultivated lands and projects 'from scratch' – emphasizing the reliance on geography or nature, and brownfield sites or *brownfields* – a term used for abandoned and built-up areas, describing what greenfield turn into in the course of civilizational expansion or objects beyond further use or development.

Brownfields diminish the standard of living and the competitiveness of individual municipalities and entire regions (Wang et al., 2023), inducing their residents to migrate to more attractive areas with better environmental conditions, and discouraging potential investors from engaging in community development projects.

According to some estimates, redevelopment is required for 5 million brownfield sites globally (Hou et al., 2023). These sites are in need of being brought back into beneficial use, after the cleaning up of contaminated soil and groundwater (Grimski & Ferber, 2001). While having been formed in the areas developed through mining industries, brownfield sites represent genuine 'techno-genic' deposits.

Brownfields are typically seen from a surface-centric, flat, two-dimensional perspective, even though large on-the-ground imprints and vast underground spaces are left in the aftermath of a mine closure, whether in Poland's Upper Silesia (Krzysztofik et al., 2012) or in the Russian Kuzbass (Cehlár et al., 2019). Post-mining, signifying the physical closure of an enterprise coupled with measures to mitigate the environmental and social impacts of its existence, can potentially manifest a declared transition from 'black' to 'green'. Yet, it operates within the context of the same 'flat' approach to brownfields. For example, Frouz et al. (2008) and Skousen & Zipper (2014) have delved into the topic of land reclamation following cessation of mining works in Czechia and the Eastern Province coal region of the United States (US). A similar type of studies has also covered post-brownfield land reclamation in East Asia (Zhao et al., 2009) and South Africa (Limpitlaw et al., 2005). Despite the widespread use of such a perspective, adhering to stereotypes that view brownfields in regions with concentrated location of mines from a flat, shallow, or narrowly literal viewpoint is risky in terms of both ecology and economic losses. The regional specificity necessitates an extension of the concept to incorporate the third dimension, along with considerations for geological deformations and dynamics of underground water and gas flows. Hence, ***the aim of this work*** is to define the concept of three-dimensional brownfields and the pertaining environmental risks and economic opportunities.

Methodology

In this paper, the findings are obtained as the result of abstraction, observation, analysis, and synthesis, constituting the core of the conceptual framework. The data sources regarding the state of structures, herein referred to as *3-D brownfields*, include materials from both desk-based research and fieldwork carried out by well-known hydrogeologists in Ukraine, particularly Evhen O. Yakovlev and others (OSCE, 2017; Dovhyi et al., 2019; Yakovlev, 2017). In terms of theory, the authors have employed the theory of common-pool resources (CPR) developed by the 2009 Nobel Prize (The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel) laureate Elinor Ostrom (1990, 2002). Within a broad comparative framework, whilst keeping its particular focus on Ukraine, this paper uses Ostrom's CPR theory to substantiate the regularities observed across the world in the development of three-dimensional brownfields in regions featuring a high concentration of mining enterprises.

Research Findings

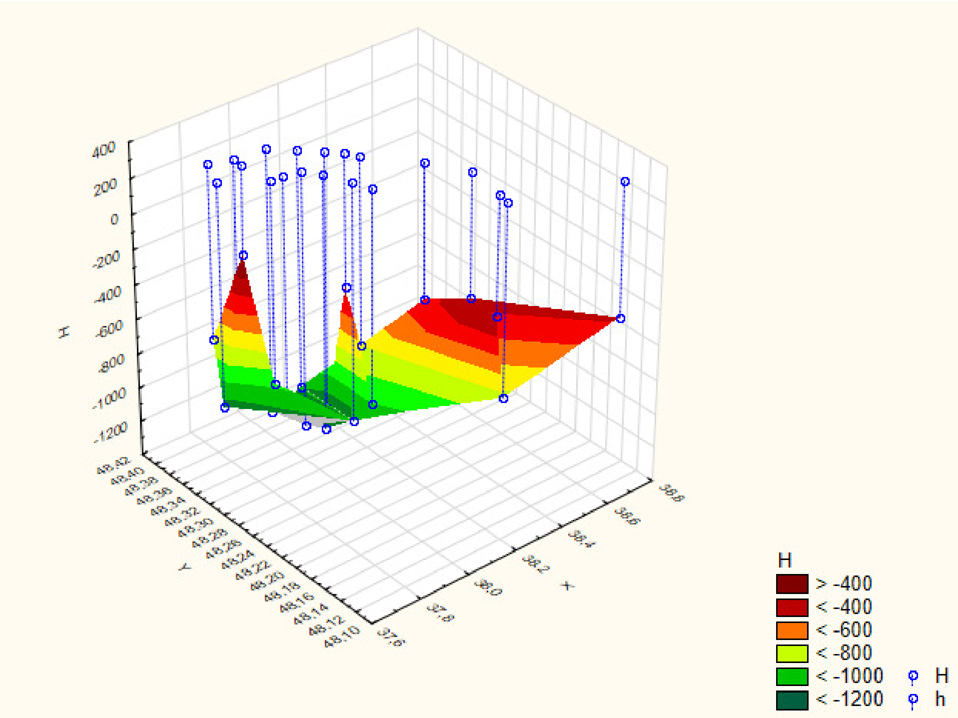
Quarries and open-pit mines are most obvious visual manifestations of 3-D brownfields. As a method of developing mineral deposits, quarrying and surface mining differ from sub-surface (underground) mining in that the latter supports *an illusion* of the integrity of the ground surface – a seemingly ordinary natural landscape or industrial scene, where only coal mine shaft towers and spoil tips (also known as slag heaps) hint at the presence of a mining enterprise. However, when one looks at a real map (see Figure 1), containing geographic coordinates of the several coal-mining towns in Ukraine's Central Donets coal basin (Donbas), including Toretsk, Horlivka, and Yenakieve, one can see a 'portrait' of an underground agglomeration – from the geodetic mark of the shaft collar +150 to +300 meters above mean sea level, up to the horizon, to -1,200 meters below sea level. The parameters of these mine shafts correspond with the data obtained by the experts from the Organisation for Security and Co-operation in Europe investigating the environmental impact and hazards of the early phase Russo-Ukrainian war in eastern Ukraine (OSCE, 2017, p. 48).

As per our interpretation, three-dimensional brownfields encompass both working and abandoned mining sites featuring buildings and infrastructure facilities on the ground surface as well as natural landscapes that have been negatively impacted by geological, hydrodynamic, and gas-dynamic processes and the disturbance of the subsoil caused by historical operations of coal mines, whether active or inactive.

Today, not only the Central Donbas coalfield but almost the entire Ukrainian Donbas is a representation of a three-dimensional brownfield. Over 150 years of intensive coal-mining, almost 10 billion cubic meters of coal and rocks have been extracted and lifted from the underground to the ground surface. The disturbance of the subsoil balance is observed across an area of 15,000 square kilometres, which is six times larger than Luxembourg. A typical coal-mining town in *Donetska oblast* (Donetsk province), with a probability of 95%, occupies an area of 5.7±2.9 square kilometres, emerging in the vicinity of a mining enterprise. One such example is the town of Bilytske, which has a population 7,764 (2022 estimate), situated near a mine of the same name. The population density of Bilytske is 3,483persons per square kilometre, which is a fifth higher than in Germany's Ruhr Area (2,919 inhabitants per km^2) – a world-renowned exemplar of old coal-mining regions. By contrast, *Dobropilska miska hromada* (Dobropillia urban commune) itself, to which Bilytske administratively belongs, has a population density of only 170 persons/ km^2 (authors' calculations based on Brinkhoff, 2023; see also, Amosha et al., 2018).

Figure 1

Map of mine shaft locations in the Central Donbas, Ukraine, 2010s



Note: *Y*–northern latitude, deg; *X*–eastern longitude, deg; *H* – vertical coordinate, m).

Cities across the region were formed through the amalgamation of mining settlements. Beneath the city of Donetsk, for example, lies a completely hollowed-out area of more than 385 square kilometres, accommodating the workings of 12 operating and 17 shut down underground mining enterprises that have been in operation since 1961, with the overall history of commercial coal mining dating back to the late 19th century. In Horlivka, the fifth largest city of the Donbas coal-fields, with 239,828 inhabitants (2022 estimate), the hollowed-out area underneath the municipality extends to 127 square kilometres, accounting for 70% of the total city council territory. It contains the workings of 10 formally functioning pits and the remnants of 5 abandoned pits (Dovhyi et al., 2019).

In line with the prevailing British tradition, the development of a coalfield typically starts with the establishment of a Joint Stock Company (Company) that would obtain the right to mine the mineral, establishing a so-called coal camp, comprising a church, a theatre, a shop, and residential barracks. This approach to commercial coal-mining was adopted in the United States, Australia, and in the Donbas, where heavy industrialisation was spearheaded by Scottish and Welsh industrialists. The Company in this situation acted not only as the mine owner, but also as the governor/manager of the entire 3-D brownfield. In this dual role, the Company held the prerogative and obligation to address both the technological issues, primarily the drainage of the subsoil, and the everyday needs of the staff and residents.

In the case of the Appalachian coalfield within the eastern US, gradual mechanization, which has accelerated since the Second World War, resulted in considerable rationalization of employment (Zipper et al., 2021). In 1950, pits in West Virginia, the key coal-mining state, employed 127,000 miners, whereas by the end of the 20th century, their number dropped to fewer than 18,000, even though the coal output reached record highs, when, in 1997, more than 180 million tons of coal were extracted in West Virginia. By 2023, the output decreased to 96. 5 million tons, with the number of miners dropping further to 12,500 (Lewis, 2023). With highly-mechanized production process, the extraction of underground coal deposits at ever-deeper levels necessitates continuously growing investment, which leads to a sharp decrease in the profitability of pits. Over time, low profitability and price volatility in global coal markets have forced many owners of pits in the Appalachian coalfield to go out of business, resulting in a long-term economic depression that engulfed the state (Amosha et al., 2018). Commercial coal-mining in West Virginia has never improved. Apart from a few success stories, including the purchase by Ukraine's *Metinvest* conglomerate of West Virginia's *Affinity* Mine, which had sizable deposits of premium-class metallurgical coal, yet remained abandoned for more than a quarter of a century, West Virginia continues to be the second poorest region in the US after Mississippi.

The state of the coal camp after the cessation of coalfield exploitation and departure of the governor (Company) has been extensively described by the American anthropologist Kathleen Stuart in her 1996 book *A Space on the Side of the Road: Cultural Poetics in an «Other» America*. Stuart's (1996) depictions of abandoned coal towns of southwestern West Virginia portray what we consider to be the highest manifestation of economic collapse – mining water rushing under a house. It is in this context of de-industrialization and abandonment that the scheme employed by Elinor Ostrom in the context of common-pool resources (CPR) comes into play. As summarized by the 2009 Nobel Prize Committee:

«It was long unanimously held among economists that natural resources that were collectively used by their users would be over-exploited and destroyed in the long-term. Elinor Ostrom disproved this idea by conducting field studies on how people in small, local communities manage shared natural resources, such as pastures, fishing waters, and forests. She showed that when natural resources are jointly used by their users, in time, rules are established for how these are to be cared for and used in a way that is both economically and ecologically sustainable» (Nobel Prize Outreach, 2023).

Ostrom's CPR theory is explained using the example of a peasant farmer who endeavours to drain the swamp all by himself in order to create a pasture for grazing animals. The farmer alone bears significant costs to achieve the result that will benefit the entire community (Ostrom, 1990). However, if he abandons the responsibility for drainage, and those who need pasture fail to assume it, that can only lead to a tragedy for the rural community. This tragedy is generally referred to as 'the tragedy of the commons', a term coined by the American biologist Garrett Hardin (1968). Similarly, if the governor leaves the coal camp and absolves the duty 'to drain the pasture', that is, to pump out the pit water, the emerging brownfield, officially or by default, would transform into a common-pool resource. Consequently, the tragedy of the commons could become a depressing reality for the individual mining community.

It would be incorrect to interpret the decline of coal-mining communities solely within the context of CPR alone. In Donetsk province, 63% of the inundated lands are located within the surface subsidence area, including 23 towns, out of 35 such urban settlements across Ukraine (GEOINFORM UKRAINE, 2014). Importantly, none of the coal pits in the region have employed backfilling of excavated spaces to prevent deformation of the surface ground. In the example with coal camps, the community could, in principle, take responsibility for brownfield drainage, even under the condition of purchasing or renting a stationary technological complex comprising a hoist and an underground pumping station. Backfilling the excavated underground space cannot be delegated to a local community, however, due to the complexity and costs involved in carrying out such an activity. The emerging dilemma locks the actors into the state of a bad, sub-optimal equilibrium. Hardin employs game theory by designing a game entitled *Commonize Costs-Privatize Profits Game* (CC-PP Game) to examine environmental issues, particularly those related to mining, in the context of natural resources depletion and increased pollution. To resolve this situation, the incentive structure should be redesigned, so that to eliminate the motivation for free-riding and make the strategy of co-operation dominant for all participants (Hess & Ostrom, 2003, p. 117). Yet, the freedom to use CPR within the CC-PP game framework leads to their destruction (Hardin, 1968, p. 1244).

Abandonment as an approach to mine closure, practised by American entrepreneurs, significantly differs from that of their European counterparts. In the EU, mine closure standards strive to ensure that the landscape is restored to its 'green', pre-industrial state as effectively as possible. Efforts are usually made to address environmental and social issues caused by the appearance of brownfields. The experience of leading European countries in ecological and socio-economic restructuring of old coal-mining areas in the UK, Germany, and France shows that post-mining recultivation is a prolonged process entailing and entails large – almost perpetual – costs, consuming up to €300 million annually in the case of the Ruhr Area (Dovhyi et al., 2019, p. 24). Following the closure of all pits across the Ruhr coalfield, 6 dewatering and 3 degassing mine operations were left to (i) maintain the level of mineralized pit waters in coal seams at the depths from 250 to 320 meters, and (ii) to prevent the accumulation of explosive methane gas at the surface (Dovhyi et al., 2019, p. 43).

Ukrainian law mandates that the resolution of all environmental and social issues stemming from the activity of a liquidated coal mine must be financed by the mine's owner. The majority of Ukraine's coal mines, primarily consisting of abandoned and loss-making enterprises, is state-owned. The funding required for mine closure projects, though considerably more modest than in the Ruhr Area, has not been sufficiently provided by the central government, particularly for social and environmental aspects. Moreover, the course of events unfolded in a way that the Russian aggression against Ukraine has dismantled the ability of the state, including the central government, to act as the paradigmatic owner, who, using Ostrom's analogy, seeks to drain the swamp all alone. The loss of government control over the coal-mining areas in eastern Ukraine has led to the immediate cessation of drainage operations in many 3-D brownfields across the war-ravaged region. Following the loss of power supply for mine dewatering pumps, sub-surface flooding commences within 6 to 96 hours, depending on the volume of the sump. In September 2015, the loss of power supply as a result of hostilities caused a 20-centimeter-per-day rise in the groundwater level in the vertical shaft of *Pervomaiska* mine (Luhanska oblast). This event eventually led to the flooding of the territory spanning three towns with a combined population of 80,000 (OSCE, 2017). Flooding the excavated underground space with water results in the subsidence of the ground surface, causing structural cracks and deformation of buildings, roads, and bridges, and can potentially lead to the release of explosive (methane) and radioactive (radon) gases pushed to the surface.

The impact of rising mine waters considerably differs across different brownfields: for instance, during the period December 2017 – May 2018, the water level in *Izotov* mine in Horlivka had risen by 13 meters. By contrast, the water level in *Rumyantsev* mine, also in Horlivka, had risen by 119 meters, while *Kalinin* mine had experienced an even more pronounced increase in underground water levels of 261 meters. During the same period, in Yenakieve, water levels in *Poltavska* and *Yenakiivska* mines had shown modest increases of 13 and 15 meters, respectively, while *Karl Marx* and *Red Profintern* mines had experienced substantial flooding reaching 112 meters and 216 meters, respectively (Dovhyi et al., 2019, p. 55-57).

Three-dimensional brownfields are peculiar for their ability to widen damaging geological and ecological impacts over a long distance, even transcending borders or demarcation lines. For example, a lignite opencast mine in Turów (*Kopalnia Węgla Brunatnego*, KWB, Turów), producing 8 million tons of brown coal annually, and generating 35 million cubic meters of waste rocks alongside, is located in south-west Poland. Yet its adverse geological and hydrological effects, including surface ground subsidence and diminishing groundwater levels, are felt across the borders in both Czechia and Germany.

Ukraine's hypsometric analysis reveals that the coal mines operating in the non-government-controlled territory and which account for 80% of all mines in the country are situated at higher elevations than those in the government-controlled territory. Consequently, the mines operating on the government-controlled side have been under increasing hydraulic pressure, elevating the risk of ecological devastation spreading well beyond the confines of the Russian-occupied Donbas. Compounding the problem further, underground mine workings are often hydraulically interconnected through so-called cross-cuts, as in *Pervomaiskvuhillia* mines in Luhanska oblast and *Toretskvuhillia* mines in the neighbouring Donetska oblast. Consequently, over time, an uncontrolled rise in groundwater levels has built up detrimental impacts on the over-ground urban areas and critical infrastructure facilities. For example, in 2018, mining waters from *Pervomaiska* mine, located in the non-government-controlled-territory in Luhanska oblast, flooded *Zolote* mine across the Donbas front line. Today, a similarly critical situation is unfolding around *Toretska* and *Tsentralna* mines (Toretsk Coal State-owned Company, Donetska oblast).

To resolve the growing problem of 'cross-border' mine water flooding, the part of the Donbas that sits on 3-D brownfields needs the creation of a CPR in the form of mine drainage operations. As the CPR theory posits, there exists two distinct groups of actors in this regard – those who participate in the creation of the common good by pumping out the pit water, and those who avoid doing so by shutting down the underground pumping stations. Such a dilemma locks the actors involved into the state of a bad equilibrium. Achieving an institutional equilibrium, as forewarned by Douglass C. North (1991), does not mean that all players are satisfied with the existing rules of the game and ensuing agreements, but rather that they find it unprofitable to alter the game.

The rising sub-surface pit waters may serve as a tangible inducement to change the rules of how a three-dimensional brownfield should be handled. Up to 760 million cubic meters of water annually flow into mine workings in the Donbas (over 200+ sites), which amounts to almost 25 cubic meters of water per second. The region's geological depression of underground water levels, that is, water drainage, is the key factor that has helped to maintain the relative balance of ecological and geological conditions. This process has served to prevent the inundation and flooding of the arable land and urban areas adjacent to the pits, where the ground surface may subside above mine workings. Additionally, the relative balance of ecological and geological conditions in the region has acted as a barrier against the release of explosive sub-surface gases (Yakovlev, 2017).

The disturbance of this fragile ecological-geological balance poses not only the threat of inundation and flooding across many cities, and of the contamination of underground and surface water intakes, but also of triggering local earthquakes and damaging the critical infrastructure, including pipelines, power lines, roads, bridges, buildings, and other facilities. This hazard appears especially acute in the Donbas, with its 4,000 chemical, iron and steel, and other heavy industrial enterprises, including Mykytiv Mercury Plant and *Yunkom* mine near Yenakiieve, which contains a radioactive capsule at the site of the 1979 underground nuclear explosion by the Soviet authorities. Thus, uncontrolled mine flooding may potentially push the fragile regional natural-techno-genic geosystem into an environmental catastrophe. The 1989 accident at *Oleksandr-Zakhid* mine (Horlivka), which led to the poisoning of miners and mine rescue workers, reminds one about the severity of geological disturbance caused by the infiltration of chemicals from surface factories into mine workings (OSCE, 2017, p. 12).

Larger mining areas and significantly greater depths (by a factor of 3 to 4) are the key drivers making the current situation with mine flooding in the Donbas a much more complicated issue than it had been previously, during the Second World War, when first the Soviets and then the Nazis flooded the pits whilst retreating from the territory in 1941 and 1943, respectively. If the territory in areas with concentrated coal mining becomes largely unsuitable for human habitation, forcing the population to leave, the local geological-ecological phenomenon risks escalating into a national or even international humanitarian crisis, akin to the Chornobyl disaster. A devastating event of this magnitude can cause irreversible disturbances in the balance and structure of the subsoil, serving as a basis for the functioning of the biosphere and ensuring safety of human life in a much broader region.

Even under an optimistic scenario, the socio-economic prospects of 3-D brownfields look dismal, almost everywhere. This contention is informed by international experience. In the US, it is not only in the Appalachian Coalfields, but also in the formerly successful manufacturing cities such as Detroit, Michigan, and Cleveland, Ohio that an inherited burden of the past leads to economic failures in the present. Similarly, the formerly mining cities and regions of England, Scotland, and Wales, as reported by the Coalfields Regeneration Trust (Beatty et al., 2019) are mired in the living legacy of past trauma. The UK's former coalfields and adjacent areas have a total population of 5.7 million, with many coal-mining towns and villages still being unable fully to recover from pit closures of the late 1980s and 1990s. Although unemployment has significantly decreased after almost forty years, there are still a large number of people, who remain economically inactive due to chronic health problems; most of the employment, education, skills, and health indicators in the former coal-mining areas linger at the bottom of the national league tables. For instance, 42% of former mining neighbourhoods rank amongst the 30% most deprived areas in Britain, registering only a 1 percentage point improvement since 2010 (Beatty et al., 2019, p. 39).

In Ukraine, coal-mining areas include nearly 20 territorial communes spanning Volynska, Dnipropetrovska, Donetska, Luhanska, and Lvivska *oblasti*, with a combined population of approximately 850,000 residents. One of the unique characteristics of the industry is that the coal-miners' skills are not transferable to other industries, posing a huge adaptation challenge for miners seeking other opportunities. Job-seeking out-migration quite often presents itself as the only alternative, resulting in rapid population loss, also known as shrinkage. Whilst urban shrinkage is a complex phenomenon (Mykhnenko, 2023), the depopulation processes in Ukraine's coal-mining towns have unfolded amidst an overall population decline across the entire region, albeit within different timeframes. Coal-mining towns in Donetska oblast experienced a *significant* population decrease since in the early 2000s: during that period, the population of some mining towns dropped by 11%, whereas the region as a whole saw only a 1% decrease. Even in relatively successful coal-mining towns, depopulation has been propelled by limited access *to* and low quality *of* healthcare services. Moreover, the primary concern of local residents is pollution and the poor state of the natural and built environment, damaged by mining activities and the use of coal for heating homes.

Even if the local stakeholders are willing to show initiative, the introduction of circular economy projects, such as the recycling of industrial waste, which brownfields are rich with, cannot be viewed as a means to ensure the survival of coal-mining towns. Circular economy can only be considered as a means to support the local community during the transition period. As highlighted by Batunova (2020), urban shrinkage cannot be halted solely through economic tools. Therefore, the strategy for the development of former mining towns should aim at 'enlightened' restructuring, aligned with the ideas of 'smart shrinkage'.

To respond effectively to the highly probable imminent ecological crisis in eastern Ukraine, it is imperative to develop a challenge-facing strategy. From the beginning, this necessitates one to acknowledge the presence of developing geological-ecological hazards in the Donbas, and to develop an appropriate national disaster management plan. It is contended that such a strategy should include (1) the establishment of an international commission to assess, via GIS remote sensing methods, the probability of a geological-ecological disaster in the Donbas, and evaluate its possible humanitarian and economic consequences; and (2) the undertaking of urgent financial, economic, administrative, ecological, and political measures as part of a national plan for managing the consequences of the emerging geological-ecological disaster in the Donbas.

Discussion and Conclusions

The prevalence of the mining industry in the domestic economy of many countries preconditions the formation of numerous brownfields in the form of industrial mining sites, landfills, slag heaps (spoil tips), and tailing dams. Brownfields emerge in the context of built-up environments that have been previously developed, in contrast to greenfield sites – virgin territories that have never been used for development. Nonetheless, even the areas that look to be completely green from the outside can be situated atop mine workings, harbouring unseen challenges.

According to the conceptualization proposed in this paper, three-dimensional brownfields should be understood as either operating or abandoned industrial sites with buildings and infrastructure facilities on the ground surface, as well as natural landscapes that are negatively affected by geological, hydrodynamic, and gas-dynamic processes, suffering from the disturbance of the subsoil due to underground or open-pit mining operations.

After 150 years of mining operations, the majority of the Donbas region has become a 3D brownfield, with mine workings of many active or closed enterprises located underneath major cities, thus, necessitating a major national government intervention There are two main approaches to mine closure: the *laissez-faire* approach, practiced in North America and most countries worldwide, and the *European* approach, characterized by a considerable degree of state intervention. European mine closure standards insist on restoring the landscape to its pre-industrialized state as effectively as possible. With this approach, the post-mining period is long and entails large – almost perpetual – costs, reaching up to €300 million annually, according to the experience of the Germany's Ruhr Area.

The condition of 3-D brownfields that have been abandoned without water drainage echoes the tragedy of the commons, as per the CPR theory, where a peasant farmer, initially taking the initiative to drain a swamp alone for pasture that would benefit many users, later abandons this duty to lazy neighbours.

The current situation of 3-D brownfields in Ukraine locks the actors into a state of a bad equilibrium. The part of the Donbas territory that is located in 3-D brownfields requires the creation of a common good – mine water disposal and groundwater drainage operations. However, since the start of the Russian invasion of eastern Ukraine, two distinct groups of actors have formed – the enterprises in the government-controlled territories, which participate in the creation of CPR by exploiting mine drainage systems, and those, who avoid this responsibility by shutting down the underground mine pumping stations.

The distinct characteristic of 3-D brownfields is their capacity to spread negative externalities. Hypsometric analysis shows that the mines in the non-government-controlled territories of Ukraine, i.e., 80% of the nation's total mine count, are situated at higher elevations that those in the government-controlled territories. This increases the risk of ecological disaster spreading beyond the Russian-occupied Donbas, because the operating mines on the Ukrainian side of the front line experience an increased in hydraulic pressure.

The disturbance of the ecological-geological balance poses a threat of not only inundating and flooding the affected urban areas, polluting underground and surface water intakes, but also of causing local earthquakes and destructing critical infrastructure facilities, including pipelines, power lines, roads, bridges, and buildings. This threat is most acute in the Donbas (Donetska and Luhanska oblasti) which are home to 4,000 heavy industrial enterprises. If the land of concentrated coal mining activity becomes largely uninhabitable, forcing the population to leave, the regional geological-ecological imbalance risks escalating into a national, or even continental, humanitarian disaster.

Even under an optimistic scenario, the socio-economic prospects of 3-D brownfields should be considered bleak. For example, 42% of the former coalfields in the UK appear amongst the most deprived 30% neighbourhoods.

The reuse and recycling of industrial waste accumulated in brownfields cannot ensure the survival of mining towns. At the same time, urban shrinkage cannot be resolved solely through economic instruments. Therefore, the strategy for the restructuring of the former coal-mining urban areas should be aligned with 'enlightened' restructuring, especially, smart shrinkage solutions.

By extending the CPR theory to 3-D brownfields, this paper makes an original contribution to knowledge and opens the underlying theory to new exciting pastures.

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