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The Issue of Environmental Resources Management in the Light of the Model of Tragedy of the Commons – Systemic Approach

Problematyka gospodarowania zasobami środowiska w świetle modelu tragedii współużutkowania – ujęcie systemowe

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Abstract

In 1968, a paper appeared in the *Science* journal outlining a macroeconomic concept referring to the problem of common use of environmental resources. Its author, Garret Hardin, stated that the natural human desire to maximise individual economic benefits led to overexploitation of environmental resources to the detriment of the whole society.

The problem brought up by Hardin is very important from the perspective of the idea of sustainable development. After all, the relationships in which the pillars, or subsystems (ecological, social and economic ones), of sustainable development remain should be harmonious enough to enable simultaneous maximisation of their objectives. In particular, the social, economic and ecological subsystems should not exclude one another. However, the tragedy of the commons is a classic example of a situation where the economic subsystem is in conflict with the ecological and social subsystems. As Hardin pointed out, this phenomenon occurs in various spheres of human activity and cannot be overcome by only technical means.

Observing the grazing of cattle on a commons, Hardin noticed that the commons became completely depleted, although this was not in the interest of the local community. It is not only in farming that ecological and social problems appeared as consequences of an individually rational economic activity. Hardin' s concept found confirmation in overexploited water supplies, depleted fisheries, cleared forests, illegal rubbish dumps, and rivers degraded by sewage.

It is in the vital interest of the society to better get to know and bring under control the mechanism that leads to exceeding of the environment regeneration capacities and results in its users starting to incur losses instead of benefiting from it. This issue is examined by a systemic approach to management which identifies the universal pattern of system behaviour referred to as the archetype of the tragedy of the commons. Thus, the phenomenon is systemic in origin, and we can learn more about its development in time (or even neutralise it) by means of the method of system dynamics. A system affected by the tragedy of the commons functions in a way that diverges from the idea of sustainable development. It contradicts not only the postulate of intergenerational justice (there is overexploitation of environmental resources which can even lead to their irretrievable loss), but also intragenerational one (actions of some users of the environment cause inconveniences that will afflict the whole society). Therefore, we cannot ignore the symptoms of the tragedy of the commons while trying to implement local ideas of sustainable development.

The article explains the mechanism of the tragedy of the commons based on the system theory using the model of system dynamics. A systemic archetype has been discussed on the basis of which a dynamic model has been developed, and a simulation of the common resource exploitation has been carried out. Further on, possibilities of preventing the scenario of resource depletion have been discussed.

Key words: environmental resources, the tragedy of the commons, archetype, system, model

Streszczenie

W 1968 roku na łamach czasopisma *Science* przedstawiony został zarys koncepcji mikroekonomicznej odnoszącej się do problemu współużytkowania dóbr środowiska. Jej autor, amerykański ekolog Garret Hardin stwierdził, że naturalne ludzkie dążenie do maksymalizacji indywidualnych korzyści ekonomicznych prowadzi do nadmiernej eksploatacji dóbr środowiska przynosząc straty całemu społeczeństwu.

Z punktu widzenia idei rozwoju zrównoważonego problem poruszany przez Hardina należy uznać za bardzo ważny. Wszak filary, a zarazem podsystemy owego rozwoju (ekologiczny, społeczny i ekonomiczny) powinny pozostawać względem siebie w relacjach na tyle harmonijnych, aby możliwe było jednoczesne maksymalizowanie ich celów. W szczególności podsystemy: społeczny, ekonomiczny i ekologiczny nie powinny się nawzajem wykluczać. Tymczasem tragedia dóbr wspólnych to klasyczny przykład sytuacji, podczas której podsystem ekonomiczny wchodzi w konflikt z podsystemami ekologicznym i społecznym. Jak wykazywał Hardin, zjawisko to występuje w różnych sferach ludzkiej działalności i nie da się go przezwyciężyć przy użyciu samych tylko środków technicznych.

Obserwując wypas bydła na wspólnych pastwiskach Hardin zauważył, że dochodziło do ich zupełnego wyeksploatowania, choć nie było to w interesie lokalnej społeczności. Ale nie tylko w gospodarce rolnej problemy ekologiczne i społeczne pojawiały się jako skutki indywidualnie racjonalnej działalności ekonomicznej. Koncepcja Hardina znalazła swe potwierdzenie w wyeksploatowanych ujęciach wód, przetrzebionych łowiskach ryb, wykarczowanych lasach, dzikich wysypiskach śmieci i zdegradowanych ściekami rzekach.

W żywotnym interesie społeczeństwa jest lepsze poznanie i opanowanie mechanizmu, który prowadzi do przekraczania zdolności odtworzeniowych środowiska i sprawia, że jego współużytkownicy zamiast odnosić z gospodarowania nim korzyści, zaczynają ponosić straty. Zagadnienie to rozpatruje systemowy nurt zarządzania wyróżniając uniwersalny wzorzec zachowania systemu zwany archetypem tragedii współużytkowania. Podłoże zjawiska ma więc charakter systemowy, a jego przebieg w czasie może zostać lepiej poznany (a nawet zneutralizowany) przy użyciu metody dynamiki systemów. System dotknięty tragedią współużytkowania funkcjonuje w sposób daleki od idei zrównoważonego rozwoju. Zaprzeczeniu ulega nie tylko postulat sprawiedliwości międzypokoleniowej (dochodzi do nadmiernej eksploatacji dóbr środowiska prowadzącej nawet do ich bezpowrotnej utraty) ale także i wewnątrzpokoleniowej (część użytkowników środowiska swym działaniem przyczyni się do uciążliwości, które dotkną całą społeczność). Nie można więc bagatelizować symptomów tragedii dóbr wspólnych chcąc zarazem wdrażać w życie lokalne idee rozwoju zrównoważonego.

W artykule wyjaśniono mechanizm tragedii współużytkowania na gruncie teorii systemów przy wykorzystaniu modelu dynamiki systemu. Przedyskutowano systemowy archetyp, na podstawie którego opracowano model dynamiczny i przeprowadzono symulację eksploatacji wspólnego dobra. Następnie omówione zostały możliwości przeciwdziałania scenariuszowi jego wyczerpania.

Słowa kluczowe: zasoby środowiska, tragedia współużytkowania, archetyp, system, model

Introduction

The concept of the tragedy of the commons has been known for almost half a century. It refers to the problem of managing the environment, a problem which closely fits in with the issue of sustainable development as it is important not only from an ecological point of view, but also for social and economic reasons. When there are many users of a common good, they tend to exert an increasing pressure on it, which results in consumption exceeding its regeneration capacities. Consequently, the good becomes less accessible or it is exhausted completely, and it is either impossible or too time-consuming and costly to restore it. It is paradoxical that the individual rationality leads to a state which is socially not optimal and in which the assimilative or regeneration capacities of the environment are exceeded. Hardin (1968) notes that the mechanism he described contradicts the concept of an *invisible hand* advocated by an economics classic, Adam Smith. In his work, Hardin refutes Smith's view that an individual who intends only his own gain is led by *an invisible hand* to promote the public interest. He also provides examples that undermine the laissez-faire belief that decisions reached individually are the best decisions for society as a whole, and so they should not be curbed. The problem of the tragedy of the commons is undoubtedly connected with the issue of freedom of human actions, a freedom that Smith advocated. However, the solution to this problem cannot be found only on the grounds of human freedom. It should be remembered that Hardin formulated his concept when he was observing rural communities grazing cattle on a common pasture. Assuming that the main reason why the pasture got depleted was the fact that it was shared by many users, a simple and obvious solution would be to divide and privatize the commons. In fact, supporters of economic liberalism often advocate privatization of the environmental goods. Almost two centuries ago, a British economist Arthur Young, who was called *an apostle of progress in agriculture* by Manteuffel, expressed the view that the magic of property turned sand to gold. Young said:

Give a man the secure possession of a bleak rock, and he will turn it into a garden; give him a nine years' lease of a garden, and he will convert it into a desert (Falkowski and Kostrowicki 2001). It is difficult to refute the argument that being an owner, in contrast to being a mere user or leaseholder, gives a powerful incentive to manage one's property responsibly. But is this incentive sufficient enough? It does happen that valuable environmental resources are overexploited by their very owners. In industry, companies abandon devastated areas recklessly. In agriculture, farmland left uncultivated loses its productivity, and over time becomes degraded and overgrows with weeds and bushes. Moreover, not all resources can be as easily privatized as, for example, forests, farmland, or development and construction areas. Inland flowing waters, sea waters, fisheries, or even air are also common goods which can be subject to degradation just like common pastures, but are inherently difficult to divide. Supporters of interventionism favor solutions in which access to public goods is administratively regulated, and supervised and controlled by the state. However, administration is well known for its tendency to grow excessively, and the more control it exercises over the society, the more prone to corruption it becomes. Furthermore, it often fails in situations that require a prompt and radical reaction typical of a private owner. The belief in the validity of administrative solutions collides with reality also in the tendency to implement laws and various procedures where the homeostatic and balancing function of free market and common sense would be more efficient. That is why, Hardin (1968) rightly pointed out that the tragedy of the commons was a type of no technical solution problem. Neither discoveries in natural and technical sciences that increase the environment efficiency, nor innovative economic or management solutions are enough to deal with this problem. If human actions cannot find a fundamental extension in morality, the situation of common goods will not improve, be it by giving people complete freedom, or by radically restricting it. According to Hardin (1968), a fundamental change should concern human values. They need to be cherished and fostered in a responsible and consistent way from generation to generation.

Respecting the nature's capacity for regeneration is one of the prerequisites for sustainable development (Durbin 2008). So why is this respect lacking in so many areas of human activity? This is because it is a kind of problem that involves the moral sphere; it is connected with a sense of constant dissatisfaction with what we have that is so characteristic of human beings and common-sense limits that should be placed on this sense of dissatisfaction. This problem is examined in an interesting way by a representative of social psychology, Philip Zimbardo. In his work devoted to the anatomy of evil, Zimbardo (2008) writes about the so-called *sins of the wolf.* The metaphor refers to the condition of being so greedy and desire wealth so much that no amount of it can ever satisfy this greed – just like it is difficult to fill the voracious wolf's throat. Hull (2007), quoting Korten states that multiplying money, which is considered to be the real wealth, has become the main pillar of the modern-day value system. It determines human actions together with all their negative socio-economic, political and ecological consequences (Hull 2007). Filled with the desire for more wealth, we draw increasingly more from what surrounds us (especially from the environment) and still are never satisfied. Moreover, when wealth becomes the overriding objective, this gives rise to conformist behavior, dishonesty, distrust and unwillingness to communicate. When such behavior patterns develop, it is impossible to avert the tragedy of the commons either by means of individual freedom, or by the strictest collective regulations. The human must mature to be able to exercise his freedom as well as to comply with rules. This maturity clearly manifests itself in being able to take responsibility for one's own actions. These issues were pointed out by a French economist Frederic Bastiat, already two centuries ago. A supporter of liberalism, he wondered whether God creating the world made sure that human interests were in harmony and not in conflict. Bastiat came to the conclusion that if God wanted good for the man, the laws of Providence cannot by themselves lead humanity to disaster. Numerous sufferings and problems stem from the fact that divine laws do not act in their plenitude as they are troubled by human solutions. The fundamental problem lies in the fact that enjoying our freedom we have to bear consequences of our choices, and not transfer these consequences onto others. According to Bastiat, any human error engenders useful suffering as long as this suffering affects the one that erred. It will quite naturally bring responsibility into his actions. However, suffering often and not by accident affects others that are free from error and then it sets in motion a misplaced solidarity. In Bastiat's view, responsibility along with the ability to connect effects with their causes, should bring us back into the way of what is good and true (Bastiat, 1850). Unfortunately, human solutions often stretch solidarity in an artificial way, which destroys responsibility and does not allow man to learn from his errors – also when it comes to environmental management.

The tragedy of the commons is not only connected with the issue of sustainable development and of human freedom, responsibility and morality that accompany this development, but also with the collective action theory. This theory attempts to explain why, under what circumstances and how people give up certain behavior patterns and take up collective action; for example, when those using a well spontaneously and voluntarily agree to comply with some rules to prevent overexploitation of water supply. What is the logic of collective action? Are there any analogies between collective action and actions taken by individuals? Is it possible to influence groups in the same way as individuals? This problem has been studied by an American economist and sociologist Mancur Olson (2012), among others. He has made a significant contribution to institutional economy, especially with regard to the role of private property, tax law, public goods and collective action. According to Olson's theory, members of a group will not work for a common good (with the exception of pure altruism) unless they personally benefit from such actions. Sufficiently strong motivation of group members constitutes the key to working towards a common goal (this can be, for example, a good condition of the environment). Unfortunately, in large groups this might be difficult, as their members can easily succumb to the temptation of passivity: *if I do not do anything, there is likely to be someone else who will take care of something that requires effort from me*. Another temptation for members of large groups is becoming a free-rider – *If I do something which is forbidden (e.g., take more water from a common well, than it has been agreed on), but others do not do that, ultimately nothing will happen*. Zimbardo (2008) demonstrates that antisocial behavior may result from a sense of anonymity, which is characteristic for large groups. So perhaps, a small number of users that know each other is the key to respecting the common good? It is hard to doubt it if we compare staircases in small houses inhabited by a few families with those in high-rise blocks. It is not just common areas in large buildings that are devastated. The same is true about bus stops, public toilets, waiting rooms at railway stations, subways, community parks, and urban beaches. The number of users has definitely a significant influence on the rationalization of the common goods use. This rationalization is also influenced by the rules agreed upon and then implemented by the users themselves. Elinor Ostrom, an American political economist who received the Nobel Prize for her analysis of economic governance of the commons, believes that people are able to effectively organize themselves to manage common goods (1990). However, it is necessary to determine a few basic principles, for example:

- define who may use a commons,
- determine to what extent a commons may be used,
- monitor whether allocated limits are not exceeded,
- familiarize users with sanctions for breaking the rules of using a commons,
- develop mechanisms for resolving conflicts,
- determine who can change the rules.

Ostrom (1990) emphasizes the role of communication, monitoring, sanctions and adaptation to changing conditions in designing mechanisms for rational management of common goods. Undoubtedly, this communication and adaptation can be greatly facilitated by a systemic approach. This approach helps to discover general mechanisms that lead to problems and can be grounded in some mind-sets which other users of the commons follow. In this way, it enables to take a holistic view of the complex reality surrounding us. It is then that we begin to see the importance of dialogue. Therefore, it is not accidental that the tragedy of the commons has been creatively expanded in the systemic approach to management. Peter Senge (2006), an American management theorist, mentions the tragedy of the commons as one of ten fundamental systemic patterns of behavior which are called archetypes. In a systemic approach, the tragedy of the commons is seen as the universal behavior observed wherever individuals use some common, but finite resource. Their individual rationality results in situations which are far from optimal; it leads to over-exploitation of the resource, and causes difficulties and dysfunctions in the operation of a system. According to Senge, this can be observed not only in environmental management, but also organization management (e.g., in the case of an office that serves a few units in some organization and is overexploited, as a result). In trade, the symptom of the tragedy of the commons may be overflowing the market niche by too many new businesses. In computing, the tragedy of the commons can be seen when a computer annoyingly slows down or completely hangs because too many programs draw from its limited memory and processor simultaneously. In transport, an example would be a congested highway when too many drivers decide to use it at the same time. Generalizing the tragedy of the commons problem, it can be stated after Senge (2008) that a system itself (i.e., a set of synergistically interacting elements) is the cause of its own problems. The influence of a system on human behavior has also been noticed in social psychology. To explain it, Zimbardo (2008) moves from the level of an individual to the level of a situation, and finally to the level of a system. According to Zimbardo, in order to understand complex patterns of human behavior, it is necessary to take into account not only individual predispositions and the situation in which the individual has found himself, but most of all, a system in which he is functioning. A systems theory suggests that the system structure determines the individual behavior. This structure is spontaneously and often unconsciously created by individuals themselves.

Garrett Hardin (1968), the author of the tragedy of the commons, repeatedly emphasized its systemic context. When describing the waste problem, he notes that the individual rationality compels him to dispose of waste and avoid the cost of purifying it. From the point of view of the individual, this does not seem to lead to the destruction of the environment. However, since this is true for everyone, we are closed into a system of fouling our own nest. Hardin also expresses the view that the morality of an act is a function of the state of the system at the time it is performed. Two centuries ago, a white man on the American Prairie could shoot the bison and cut out only its tongue (considered to be the delicacy), discarding hundreds of kilograms of meat. Such behavior was not considered wasteful. Similarly, no one was concerned too much about polluting rivers, because it was believed that flowing water purified itself every 10 miles. Today this would be difficult to accept. Another example of being *locked in a system that Hardin gives is that of users of a common pasture: (...) each man is locked into a system that compels him to increase his herd without limit, in a world that is limited*.

The tragedy of the commons is a serious and complex problem, and it is closely connected with the idea of sustainable development. There can be no sustainable development if the system is persistently embedded in the tragedy of the commons. Therefore, taking into account the systems theory, it is worth exploring in more detail this mechanism of being locked in a system in order to find some solution to the problem. This will be done by analyzing the archetype, constructing a model of system dynamics and simulating the common use of the environmental resource.

A systemic model of the tragedy of the commons

Peter Senge, the author of the *fifth discipline* – a systemic approach to management, states that the tragedy of the commons occurs when people benefit individually by drawing from common resources (Senge et al., 2008). Individuals keep intensifying their use of the commons until they start to experience severely diminishing returns and difficulties in the operation of the system. The commons include not only natural resources. The tragedy of the commons affects public roads, open space, time and capital, human productive capacity, and even the size of the market – simply speaking, everything that different groups of people can jointly use. Senge (2006) states that when we experience the tragedy of the commons, the system sends us a signal that there is some problem which cannot be effectively solved by an individual, but requires cooperation of all users. This confirms the importance of communication and dialogue, which were postulated by Ostrom (1990) as the first step towards the rationalization of resource management. The symptoms of the tragedy of the commons are increasing difficulties in the use of a common good, difficulties that require more and more effort from the users. As the total activity of resource users increases, individual benefits increase at a significantly slower rate and after reaching the peak values, they begin to fall. Finally, the total activity collapses, as well.

For the sake of simplicity, the tragedy of the commons archetype considers the activity of two users. To construct this archetype, Senge et al. (2008) use two interrelated archetypes of limits to growth, which share the resource availability constraint (Fig. 1). Alongside with the scale of total activity, the constraint determines how much users A and B benefit from their individual activities.

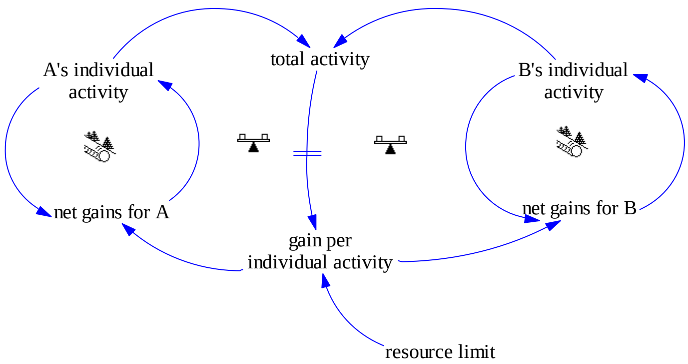

Figure 1. Systemic archetype of the tragedy of the commons. Source: own study based on Senge, 2006

The archetype consists of two reinforcing loops and two balancing loops (Fig. 1). Reinforcement results from intensification in the individual's activity, which brings more benefits, and these in turn contribute to intensification of the activity. Individual activities of users A and B are summed up to give the total activity. The closer this total activity approaches the natural resource limit, the more it will restrain the benefits from individual activities. Balancing loops show the influence of the total activity of A and B on their individual benefits.

By combining elementary structures of positive (growth driving) and negative (balancing) feedback loops, the archetype of the tragedy of the commons helps to understand the logic of the system. It also indicates how its performance can be improved. The first step towards this improvement is involving the resource users in a dialogue. Thanks to the archetype, they can clearly see the harmful structure that they create themselves, and then they can jointly take up the challenge to change it. It is worth recalling that acting on one's own cannot avert the tragedy of the commons. Senge (2006) emphasizes that systemic archetypes are to change our perception so that we can clearly see the operation patterns in systems and their reinforcement effect. In this context, let us mention an interesting example of a team working on the luxury model of Ford in the 90s (Senge et al., 2008). It was equipped with so many electrical devices that their total energy demand significantly exceeded the battery capacity. However, the designers did not want to give up any of the components. Instead, they sought solutions by trying to increase their functionality, which would justify the allocation of a limited amount of energy from the common resource. Only when the employees involved in the project took the effort to understand the tragedy of the commons, did they realize that the system pushed them towards achieving their own goals, rather than optimizing the whole system (Senge et al., 2008).

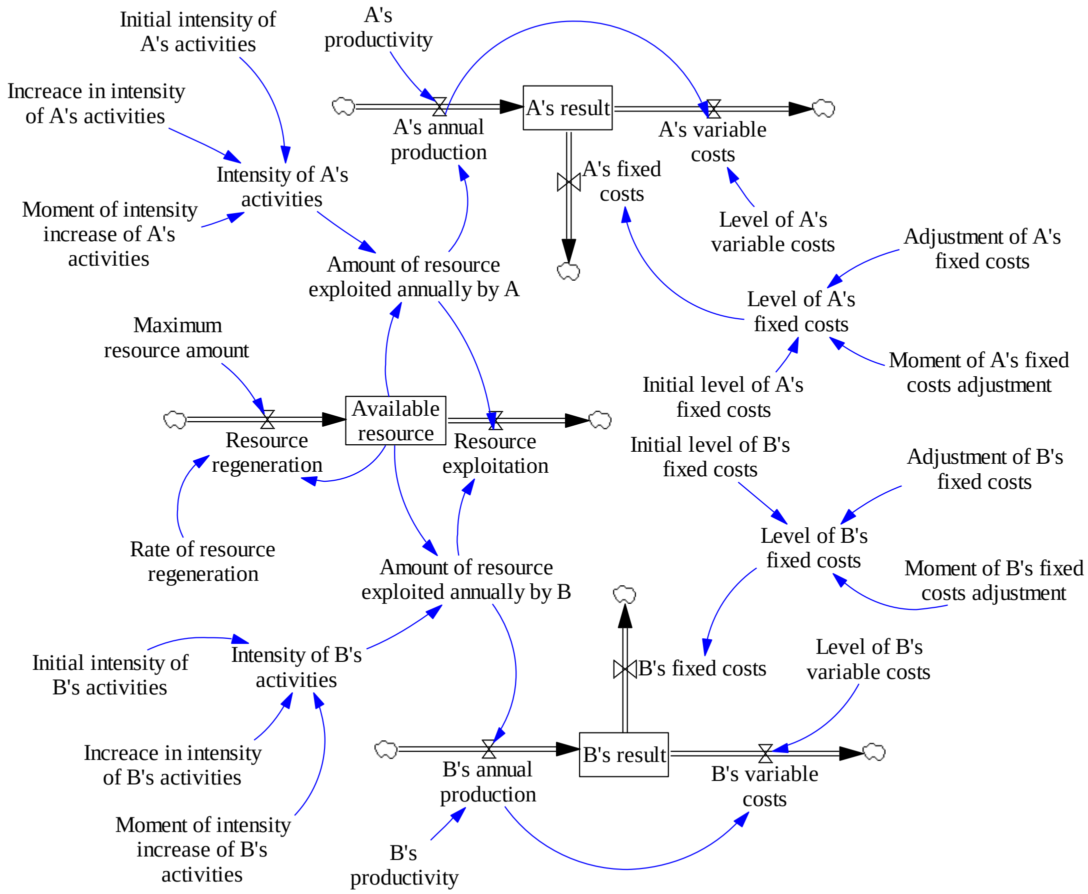

Figure 2. Flow diagram of the model of the tragedy of the commons. Source: own study

The use of archetypes is not limited to discovering the general structures of systems, which are sometimes created by man and which he is always part of. Archetypes are also useful as the starting point for developing dynamic models, which allow to simulate systems and to observe different scenarios of how they function over time (Fig. 2).

Let us assume (as in the case of the archetype presented above) that we have two users (A and B) of a common good with a limited capacity for self-restoration. The capacity will be described by the parameter, which we will call the resource recovery rate. Additionally, let us assume that even under the most favorable conditions, the resource cannot exceed a certain maximum size, which is connected with the limited carrying capacity of the environment[1]. The rate of resource consumption will depend on how much of it is left at a given point and how intensively users A and B benefit from it. The intensity may, but need not be constant. Specifically, according to the archetype of the tragedy of the commons, it is increasing over time. The results of the users' activities will be determined by their production and costs connected with it. Both users, acting reasonably, will look for opportunities to maximize their results. Both of them will be forced to bear fixed costs independent of how much they produce. The production volume is expressed by the simple function of the resource amount obtained by the user and his productivity (i.e., the relation between production and the amount of resources that were used up to carry it out). Environment users will bear variable costs expressed by the product of the annual production and the parameter describing the level of variable costs (Fig. 2).

For the sake of simplicity, reinforcing loops showing that the intensification in the individual activity of the user brings more benefits, which in turn contribute to the activity intensification, were omitted in the model. This pattern, however, was simulated by modifying the intensity of users' activities in one of the scenarios presented further on.

To create the model described above, the Vensim software has been used. In the first scenario, it is assumed that both users will draw from the environment with the same moderate initial intensity, which will remain unchanged for the entire duration of the simulation. In every calculation period, the resource

[1] This is the case with groundwater intakes, farmland resources, pastures, forests, wild game or fish stocks, to name a few.

will be depleted by roughly 1/3 of its size, starting with the maximum (100%) at the beginning of the simulation. Both users will bear the same fixed and variable costs. A's activity will be characterized by constant productivity enabling to produce one unit of the product from any two units of the environment good. On the other hand, B will have lower productivity and will need more than three units of the resource to produce one unit of the product. For the purposes of the model, it is assumed that unless completely exhausted, the resource will be able to reproduce itself according to the function – at most, by half of its amount per year. Once the limit of its carrying capacity is reached, the resource recovery rate will drop to zero[2]. The simulation time has been set for 30 years, and the simulation step: dt = 1. A set of equations describing in detail the model and its parameters, has been generated with Vensim. It is as follows:

Available resource = INTEG (Resource regeneration – Resource exploitation, 100)
Amount of resource exploited annually by A = Available resource * Intensity of A's activities
Amount of resource exploited annually by B = Available resource * Intensity of B's activities
Intensity of A's activities = Initial intensity of A's activities + RAMP (Increase in the intensity of A's activities, Moment of intensity increase of A's activities, 30)
Intensity of B's activities = Initial intensity of B's activities + RAMP (Increase in the intensity of B's activities, Moment of intensity increase of B's activities, 30)
Initial intensity of A's activities = 0.15
Initial intensity of B's activities = 0.15
Moment of intensity increase of A's activities = 0
Moment of intensity increase of B's activities = 0
Increase in intensity of A's activities = 0
Increase in intensity of B's activities = 0
A's fixed costs = Level of A's fixed costs
B's fixed costs = Level of B's fixed costs
A's variable costs = A's annual production * Level of A's variable costs
B's variable costs = B's annual production * Level of B's variable costs
Maximum size of the resource = 100
Level of A's fixed costs = Initial level of A's fixed costs – STEP (Adjustment of A's fixed costs, Moment of A's fixed costs adjustment)
Level of B's fixed costs = Initial level of B's fixed costs – STEP (Adjustment of B's fixed costs, Moment of B's fixed costs adjustment)
A's initial fixed costs = 2
B's initial fixed costs = 2
Moment of A's fixed costs adjustment = 0
Moment of B's fixed costs adjustment = 0
Adjustment of A's fixed costs = 0
Adjustment of B's fixed costs = 0
Level of A's variable costs = 0.2
Level of B's variable costs = 0.2
A's annual production = Amount of resource exploited annually by A * A's productivity
B's annual production = Amount of resource exploited annually by B * B' s productivity
A's productivity = 0.5
B's productivity = 0.3
Resource regeneration = Available resource * Rate of the resource regeneration * (1 – Available resource / maximum size of the resource)
Resource exploitation = Amount of resource exploited annually by A + Amount of resource exploited annually by B
Rate of resource regeneration = 0,5

The first scenario does not show the tragedy of the commons yet, though in the first 10 years of the simulation, the amount of available resource decreases rapidly (Fig. 3).

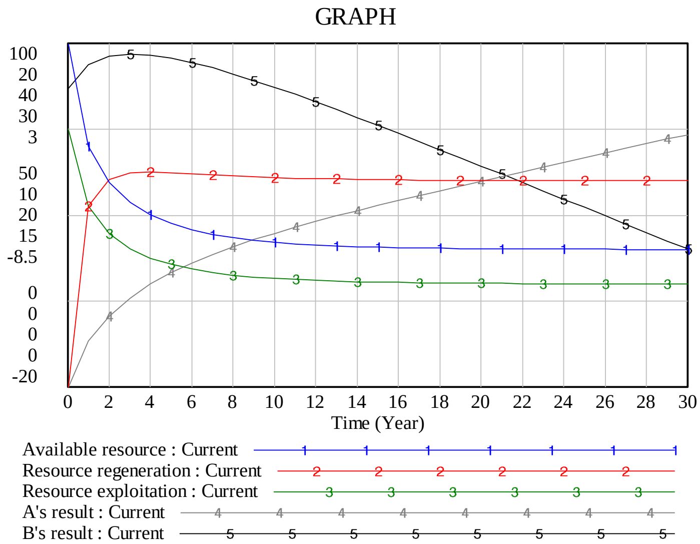

Figure 3. Model of the tragedy of the commons – scenario 1, source: own study

During this period, it regenerates more slowly than it is exploited. After 20 years, the resource is depleted to 40% of its initial amount. At that point, we can talk about a relative balance. Because of the moderate total activity of both users (which is constant throughout the whole simulation), the resource consumption rate is almost the same as its recovery rate. The results of the resource users, however, show two different scenarios due to their different productivity. In the first three years, these results are increasing, but later on only user A, whose productivity is higher, is able to improve his result year by year. After the third year of the simulation, the result of B gradually gets worse and after 10 years, it equals zero. Without adjusting its activities, user B would end up with a negative result because the benefits generated by his activity would not be sufficient to cover fixed costs (Fig. 3).
What (except for giving up his activity) can the environment user do if he is not able to significantly reduce the costs of his activity or improve his

[2] Let us note that the amount of available pasture grass has its absolute limit just as the fish stock, groundwater or wild game – when this limit is reached, the resource can no longer increase.

productivity in the short term? Taking into account the fact that he still bears fixed costs (no matter how big his production is), he may try to increase the intensity of resource exploitation by processing it in such a way that will allow surplus production in relation to the costs incurred. Let us consider, therefore, a scenario in which user B will be gradually increasing the demand for the available environment good by 1.5%/year starting from the fourth year (i.e., from the time he notices a decrease in his productivity) (Fig. 4). This behavior is reflected in the model by modifying the parameters of RAMP function, a function which is used to describe the intensity of B's activity (see the model equations). The moment of the intensity increase will take the value of 4, and the intensity increase of his activities will equal 0.015.

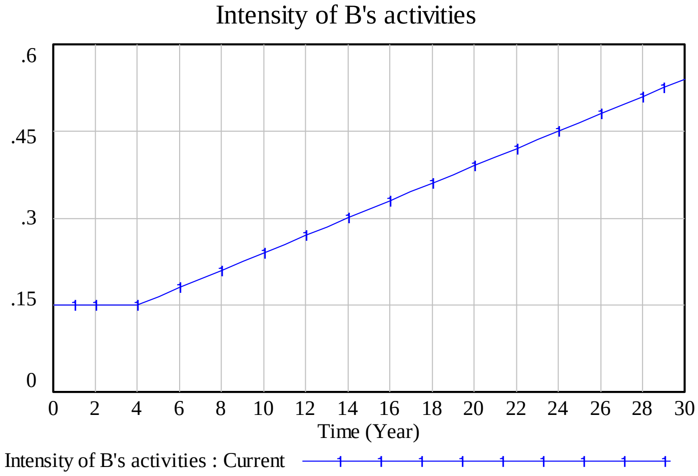

Figure 4. Increase in the intensity of B' s activities in the fourth year of the simulation, source: own study

Consequently, already half-way into the simulation time, user B will draw from the common resource more than both of them have done so far. By the end of the simulation, he will have used more than half of the available resource (Fig. 4).

Increasing the scale of his activities, user B will maintain his result at a similar level for several years (Fig. 5). However, excessive exploitation of the resource cannot prevent the failure of his business. This failure will just be postponed by 10 years. User B will not only finish the simulation at a loss, but also will contribute to the losses of A, whose result will become negative in the 26th year of the simulation. At the end of the simulation, both users will have suffered significant losses. These result from the fact that their total consumption has exceeded the regeneration capacity of the environment so much that after 30 years the available resource has shrunk to less than 3% of its original size (Fig. 5). If user A wanted to improve his result by taking more from the commons, the resource would be completely exhausted in a very short time. Its regeneration capacity would be lost, and both users would have suffered even greater losses. This would be a typical scenario of the tragedy of the commons. With many users of

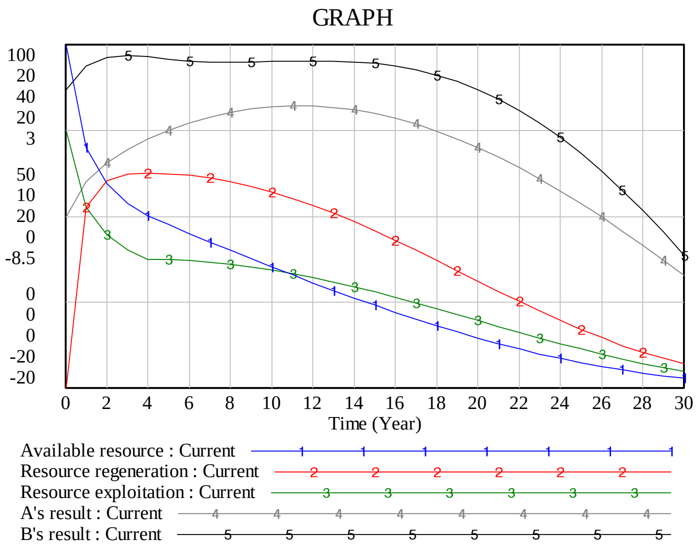

Figure 5. Model of the tragedy of the commons – scenario 2, source: own study

a common good, such a scenario seems very likely. Olson (2012) aptly states that when multiple users compete for the same public good, no one will feel that it is easier available if only one person reduces his demand. Let us also recall Hardin's reflection (1968) that a reasonable individual locked in the system of the tragedy of the commons will seek to increase the scale of his activities rather than to reduce it. This problem can only be resolved by means of communication and cooperation of all users (Senge, 2006). A dialogue is the prerequisite for sustainable management of a common good. However, as it is emphasized by Ostrom (1990), the dialogue alone, without monitoring and sanctions, is not enough.

To solve the problem of the tragedy of the commons, the users need to jointly determine the rules for using the good and to monitor both the condition of the commons and whether the limits agreed on are not exceeded. It is also necessary to introduce sanctions that will determine how to punish the user who uses up more that he has been allowed to (by modifying the model, it would also be possible to simulate what effect these sanctions would have on the resource improvement). These rules and sanctions would be presented as new feedback loops in the model. They adjust resource consumption to the pace of its recovery. For lack of space, this modified model will not be shown here. Let us assume, however, that users A and B, observing environmental impacts of their activities jointly agree to limit exploitation of the commons so that it does not exceed some predetermined value. In such a situation, even if they were incurring losses they could minimize them by controlling the size of available resource year by year and not allowing it to become completely depleted. It is also possible that the feeling of shared responsibility for the commons would make them cooperate more closely with each other and exchange experiences that would lead to improved productivity and reduced costs. It can be easily indicated what target productivity and/or what level of fixed costs would enable them to share the resource without exceeding a certain determined limit of its exploitation. Referring to the first scenario (Fig. 3), let us note that it would be sufficient if user B slightly increased his productivity (up to a level reached by A) instead of seeking solutions in increasing his demand on the common good. Let us note that user A would also be interested in exchanging experience, as his result heavily depends on the resource availability, and so not on its increased consumption by B. With other parameters remaining the same, both users could carry out their their activities depleting the resource to only 40 % of its maximum size.

With the help of the model, one can ask a question about the costs: how much would user B have to reduce the costs to make his business profitable without increasing the pressure on the environment and without increasing productivity? Obviously, there are some categories of costs that cannot be avoided, but some of the fixed costs can be reduced by working together in a group. Let us assume that in this way, user B will manage to bring down the fixed costs to 1/4 of their initial amount in the fourth year (Fig. 6).

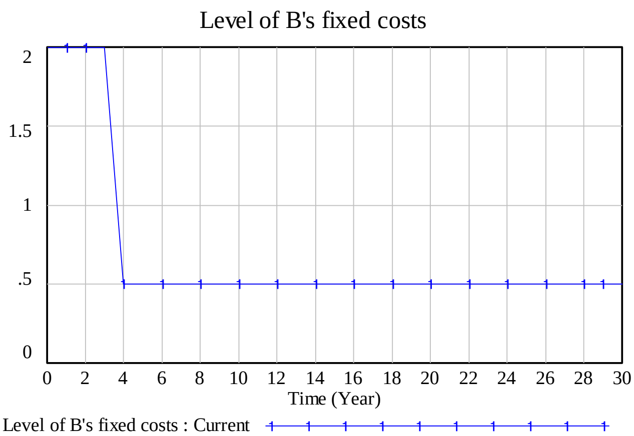

Figure 6. Reduction of the fixed costs by user B in the fourth year of simulation, source: own study

By reducing fixed costs, even at lower productivity, user B would get the result which is only slightly worse than that of user A (Fig. 7). This scenario was tested by restoring the original settings of the model and by modifying the parameters of STEP function used to describe the fixed costs incurred by B. The adjustment moment of fixed costs was set to equal 4, and its value was set at 1.5 (Fig. 6). The resource is not depleted below the level agreed on, and both users conduct their activities at a profit – though each of them with different productivity and at a different cost (Fig. 7).

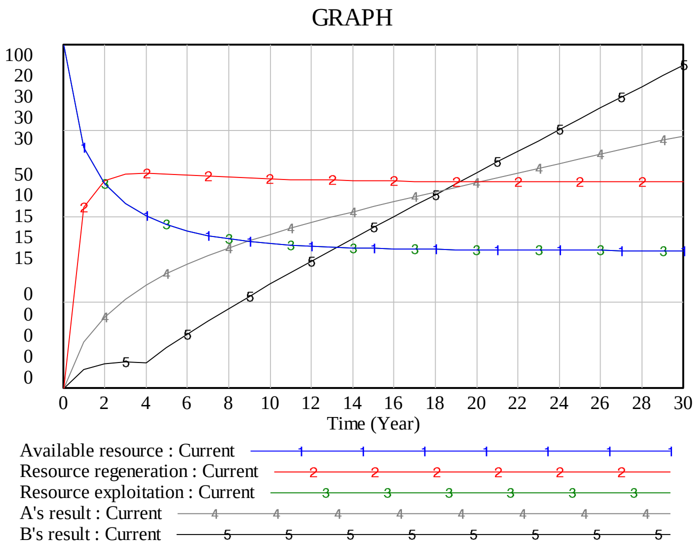

Figure 7. Model of the tragedy of the commons – scenario 3, source: own study

Summary

The tragedy of the commons reveals some truths about the functioning of systems, truths which are often underestimated. Firstly, the system components have mutual influence on each other. Components of sustainable development also interact continually and the dysfunction of one of them (for example, of an ecological component) must affect the remaining ones (social and economic components). In addition, modifying only some points of the system does not always bring about its overall improvement. In the case of the tragedy of the commons, it is not enough to change the operation of one element. To effectively eliminate the cause of the growing unsustainability, it is necessary to introduce some rules that everyone will obey. These rules constitute a purely technical solution. However, the formulation of these rules, social acceptance and compliance with them is a moral issue, which was clearly emphasized by Hardin.

The tragedy of the commons takes place when there is no communication in society and there is no holistic approach to the problem that cannot be solved individually. One farmer, reducing the size of his herd will not improve the poor conditions of a common pasture. One fisherman, limiting the size of his catch, will not save the dwindling fish stocks exploited by hundreds of fishing boats. The agreement of all resource users is difficult, because when it comes to common goods, their interests not only converge, but also conflict. We are all interested in benefiting from the environmental goods. What we do not notice is our shared interest in bearing the responsibility for protecting these goods. We would like to benefit from them regardless of what others are doing. Overcoming this way of thinking seems to be particularly important in order to implement the idea of sustainable development in the local life. How can we convince the system users of the fact that subordinating their individual rationality to the priority of social optimality can be in the interests of all and each separately? Presenting the systemic archetype which reveals how the tragedy of the commons originates could make a persuasive argument. It would also be convincing to present the model of system dynamics and together discuss different scenarios. The solution to the tragedy of the commons can be found when the resource users enter into a dialogue, recognize common problems and share the responsibility for the environment. Cooperation, mutual learning and exchange of experiences may help to overcome the resource limit. The tragedy of the commons is a characteristic of systems that forces us to cooperate. As Bastiat rightly noted (1850): *In the state of isolation, our wants exceed our productive capacities. In society, our productive capacities exceed our wants*.

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