Management of contaminated forests

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Abstract

This paper examines the main radioecological issues, the consequence of which are the distribution of doses for critical group of populations living in the vicinity of contaminated forest after the Chernobyl accident and the effects on the forestry economy. The main problems that have to be tackled are to avert doses for the population and forest workers, mitigate the economical burden of the lost forestry production and comply with the permissible levels of radionuclides in forest products. Various options are examined with respect to their application, and their cost effectiveness in terms of dose reduction when such attribute appears to be relevant. It is found that the cost effectiveness of the various options is extremely dependant of the case in which it is intended to be applied. Little actions are available for decreasing the doses, but most of them can lead to an economical benefit.

1. Introduction

Although reducing the doses for populations is the aim of implementing remedial actions for sites contaminated during the Chernobyl accident, the possible options are largely dependent of economical issues. As shown by the example of Ukraine, the allocation of financial compensation represent the major part of Chernobyl budgets (figure 1). The general economical situation in the CIS has also an important impact on the existing situation of the consequences of the Chernobyl accident and the management routes which can be implemented. It becomes obvious from the factual behaviour of people living in contaminated areas, that no successful remedial action can be achieved without people involvement. A way of involving people in remedial actions could be found in options likely to provide some additional economical benefit by the introduction of new profitable activities such as for example, the production of biofuel using rape seeds, or the amelioration of crop yields applying high doses of fertilisers. The cost-benefit analysis of the countermeasures already applied, for example in Ukraine showed that the cost of the averted man sievert is very expensive [1]. It may be proposed that the cost of the averted dose could be partially compensated by the additional economical benefit of economy enhancing options. The economical situation in the CIS is also likely to determine the increasing consumption of food from private farms, or the use of food from forest ecosystems such as mushrooms, in spite of bans.

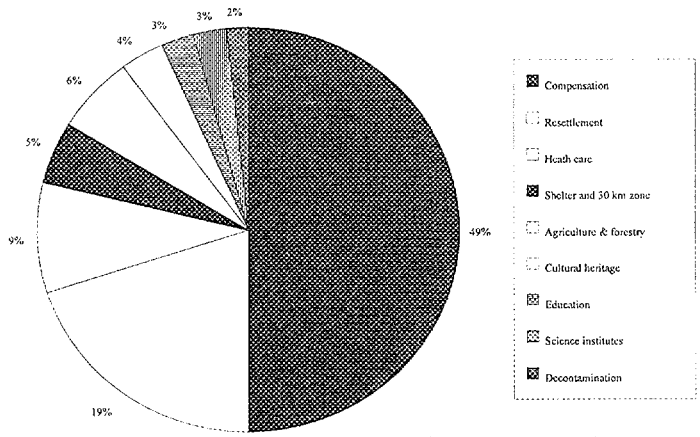

Figure 1: Chernobyl budget in Ukraine in 1993. This budget represents 12% of the national budget. (After [1])

Indeed, except bans, little can be done to mitigate the doses from forest ecosystems. A number of agricultural countermeasures have been applied after the Chernobyl accident, but their application to forest ecosystems may lead to disrupt the delicate equilibrium of forest life. Forest occupy a significant part of terrestrial ecosystems exposed to various kind of pollution. Forest health is therefore becoming an important issue in connection with the emerging concern for global changes on the earth planet. The general problems of forest management, which are pivotal environmental issues, do not disappear after a nuclear accident. On the contrary, the necessity to take care of forests becomes more important with respect to items such as fire preventing, or tree felling for sanitary purposes. Concerning forest fires, it can be enlighten that the areas of forest fires in Russia represent 5,5% of total forest areas, and are 7,5 times larger than harvest areas [2]. This proportion is likely to apply to contaminated forests also. Moreover, the reforestation of contaminated agricultural fields has been recognised as a pertinent option. This also leads to broaden the task of contaminated forest management.

In addition, it becomes sensible in certain countries such as Russia, that the transition to market economy necessitates the reorganisation of the system of forest management. It is thought that the new system could be a combination of market mechanisms and regulations applied to forest use, regeneration and protection which could be financed by forest revenue [2]. Indeed, the evidence that forest possess a substantial economic value that should be not forgotten in evaluating the consequences of radioactive polluted forest was mentioned by earlier authors [3]. Therefore, the role of economy appears to be of primary importance for the management of contaminated forests.

It is appearing that natural and forest ecosystems provide a significant complement to the diet of certain group of populations such as forest workers. Moreover, it was reported that the ratio of the fluxes of radionuclides over the fluxes of energy was higher from natural and forest ecosystems

than for agricultural ones [4]. As result, official dose records indicated the critical situation of forested areas, with dominating internal exposures in certain cases. Indeed, the behaviour of radionuclides in forest ecosystems exhibits peculiar features which take a large part in the resulting dose distributions and the subsequent problems to be solved as well as the options of forest management that can be proposed. On the basis of forest radioecology, the purpose of the present study is to review the various problems of forest management, to examine a set of various options with respect to their practical application and some elements of cost benefit analysis.

2. Forest radioecology

It is generally agreed that very little caesium is lost from forest ecosystems, and usually more than 90% of the deposited activity remains distributed in the upper organic horizon, especially in boreal forests.[5-8]. The main cause of ^{137}Cs removal from the ecosystem is the radioactive decay. Strontium-90 is known to exhibit a higher mobility. However, its affinity for organic substrate lead it to remain in the upper organic horizon of forest soils. [9]. This was namely observed during the field campaign carried out by the authors in 1994 in the Belarus part of the 30 km zone of Chernobyl in the framework of the ECP/4 project (Figure 2). This long time residence of radionuclides in the soil has a repercussion on the contamination of mushrooms which exhibit the highest transfer factors (Tf, equation 1) of any kind of forest vegetation [7].

$$\text{Equation 1 : } Tf = \frac{\text{Activity in the plant Bq .kg}^{-1}}{\text{Activity in the soil Bq . m}^{-2}}$$

Mycorrhizae groups are the most effective accumulators. Moreover, the most tasty mushrooms belong to this group which also includes the largest number of edible species. Transfer factors of up to 23 and 396×10^{-3} $m^2.kg^{-1}$ have been recorded on sandy and peaty soils respectively. Using a Tf of 20 $m^2.kg^{-1}$, Tikhomirov has calculated a dose of 1,5 $mSv.year^{-1}$ for a deposition level on the soil of 0,5 $MBq.m^{-2}$ and an annual consumption of mushrooms of 10 $kg.year^{-1}$ which is likely to be the usual diet in the CIS [7]. Balonov mentions that mushrooms may contribute to up to 70% of the dietary intake of ^{137}Cs (cited in [7]).

In comparison, berries are seemed to have a minor contribution to the ingestion dose. Doses of 0,02 to 0,03 $mSv.year^{-1}$ have been calculated for the same areas as those where the doses from mushrooms were of 1,5 $mSv.year^{-1}$[7].

A variable part of ^{137}Cs inventory is distributed in the stands, depending mainly of the soil type and the age of trees. In Sweden, for a mixed Spruce and Scots pine forest of 44 years on podzol, up to 14% of the weapon fallout inventory was found in the trees after a 14 year period [3]. In this case a transfer factor of 0,0014 $m^2.kg^{-1}$ was found for wood This value is consistent with Tf already observed in Belarus or likely to be reached within the next five years for similar ecological conditions [10]. The prediction of radionuclide migration in wood stands is of course of paramount importance for planning the production of contaminated wood. Caesium exhibit a peculiar behaviour in conifer wood in that it trends to concentrate in core wood and contaminates

the biomass produced during the time that preceded the contamination of the tree. Weapon fallout ^{137}Cs was found to contaminate the wood formed in 1914 in Japan and the United States of America [11, 12]. Strontium in conifer wood remains located around the rings corresponding to the year of pollution and such a behaviour is observed for both Cs and Sr in deciduous trees.

The contamination of games is also an important question but it is beyond the scope of this paper.

3. Problems to be solved

3.1. Monitoring of contaminated wood

The ^{137}Cs contamination of wood depends mainly of the soil properties. Therefore, it is weakly correlated to the deposition level on the soil. As defined to the equation 1, the transfer factor is not a good predictive parameter. Models involving more relevant parameters have been proposed [10], but so far, the map of contamination is still the main basis used by forest enterprises for choosing the areas where to cut the trees. The authors were told during their visit to the forest enterprise of Khoniky in Belarus that wood exceeding permissible levels is found in relatively clean areas when clean wood is found in areas above 1,5 $MBq.m^{-2}$. Therefore, due to the uneven distribution of ^{137}Cs deposition, it is thought that monitoring the wood contamination using only sampling procedures and laboratory measurements which are currently used, may lead some contaminated wood to escape from the control and clean wood unnecessarily withdrawn from the market.

3.2. Compliance with permissible levels of radionuclides in wood

The wood which does not comply with permissible levels is currently stored in contaminated areas. In Belarus this wood, amounts 2.10^5 $m^3.year^{-1}$ and the amount of standing wood in mature forest in the zone of 0,5-1,5 $MBq.m^{-2}$ (table 1) is estimated at 2 millions of m^3. The more stringent limitation applies for fuel wood with a permissible level below 740 $Bq.kg^{-1}$ of ^{137}Cs (figure 4). Wood with ^{137}Cs levels of up to 3700 $Bq.kg^{-1}$ may be used for various purposes such as keeping cases as well as house keeping. However, it seems likely that such a wood may at least end in fire after a time of normal use according to permissible levels, being known that the best way to manage wood waste is the incineration. Although the resulting doses from the uncontrolled use of contaminated wood for fire are thought to be negligible, to make coherent a system of contaminated wood management, it seems that a specific destination may be proposed for such contaminated wood.

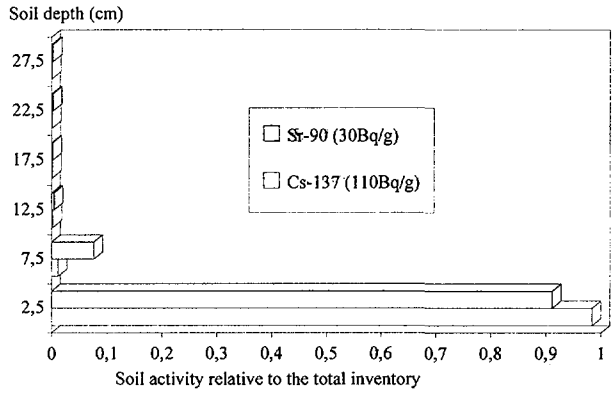

Figure 2 : distribution of radionuclides in a forest soil. Savichy, Belarus, pine forest on podzol, 1994. The absolute numbers in the legend refer to the 5 cm upper layer.

3.3 Doses for workers in forest and industry

The measurements performed during the author's field campaign in Savichy, Belarus, in 1994 gave an average dose rate of about 2,9 $\mu Sv.h^{-1}$ for a deposition of about 1,1 $MBq.m^{-2}$. Assuming that workers would stay 500 $h.year^{-1}$ to this place, this would result in a dose of 1,45 $mSv.year^{-1}$. This observation is quite consistent with the doses recorded in the Belarus State Radioecological Reserve in 1994 (figure 3). It was noted during the author's visit to the forest enterprise of Khoniky in Belarus in 1995 that trees are mainly felt using chain saws and that tree felling machines are seldom used.

The fluxes of radionuclides in wood pulp industry have been studied in Sweden and some possible dose formation pathways examined [13]. Assuming that similar pulp processing techniques are used in the CIS, the dose received by a CIS worker staying in the conditions described in the Swedish study can be calculated. On the basis of the permissible level for the wood used for pulp i.e. 3800 $Bq.kg^{-1}$, a dose rate of up to 2,3 $\mu Sv.h^{-1}$ would be received from a pile of contaminated ashes. It can be noted that this dose rate is similar to this recorded in the forest.

Table 1 : Contaminated forests for restricted activities, i.e. above 0,18 $MBq.m^{-2}$,

Country	Km^2	% of forest areas
Belarus	3670	5,45%
Russia	1350	0,02%
Ukraine	1420	1,43%

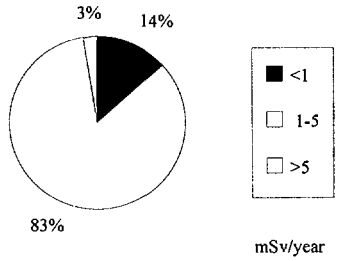

Figure 3 : External doses for forest workers in the Belarus State Radioecological Reserve in 1994 : % of the 400 surveyed workers and doses in $mSv.year^{-1}$

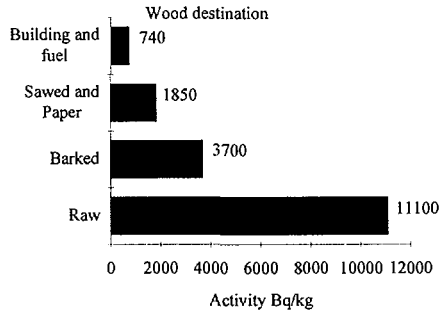

Figure 4 : Permissible levels for wood in Russia

3.4. Economical burden from the lost forest production

The losses of forest production after the Chernobyl accident have been calculated in Belarus [5]. The absolute figures of economical losses are not easy to determine because of the difficult evaluation of currency rates, but it is shown that the losses of non woody forest products are about 16 times as high as this of lost wood products. A significant part of the non woody products are components of the food chain to man, such as mushrooms, or forest pastures. The losses of wood are the consequence of, on one hand, the wood exceeding permissible levels and on the other hand the diminishing forest care because of high doses for workers and subsequent forest production. The losses of mushrooms are quoted to about 1000 tons per year. However this figure may be theoretical since it is observed that contaminated mushrooms are still consumed by the population and lead to an other kind of problem examined in the next paragraph. The same may apply for forest pastures which are known to have a significant contribution to the internal dose through the consumption of contaminated milk. But contrarily to mushrooms, pastures as well as milk can be decontaminated.

3.5.Internal doses after eating contaminated mushrooms and berries

As previously shown in this paper, berries have a minor contribution to the dose and may cause a negligible problem, when mushrooms are among the main pathways of dose distribution. It was reported that for mushroom eating populations, up to 60-80% of the internal dose come from mushrooms [4]. It was proposed [7] to implement a strict interdiction to pick-up contaminated mushrooms, using an accompanying measure which would consist in supplying the population

with mushrooms imported from clean areas. But it is seemed that the availability of clean mushrooms may not be guaranteed since mushrooms come from the natural production which cannot be managed on request.

4 Possible options of forest management

4.1. Standing tree monitoring

This option is intended on one hand, to decrease the doses from the use of contaminated wood escaped from control procedures and on the other hand to avoid loosing not contaminated wood which may have been miss classified as contaminated. The evaluation of the dose that can be avoided is difficult to achieve. It is likely that since wood does not inter the food chain, these doses may be very low. However for the need of a coherent policy of contaminated forest management, poor practices of wood control should not exist. A prototype of a counter for standing tree monitoring is currently being developed by the Institute of Nuclear Problems, Belarus State University. But so far, no information is available on the relevance of this option.

4.2. Use of tree felling machines

One tree felling machine can replace 12 loggers cutting the trees by hand using a chain saw machine. For the driver of the tree felling machine, the dose inside the cabin can be evaluated from the measurements performed in the framework of the ECP/4 project. It turned to about 30% of the dose outside the cabin, i.e. the dose received by the loggers. Therefore, using a tree felling machine in contaminated areas instead of 12 chain saw machines may achieve a collective dose reduction factor of about 40. The price of a tree felling machine which can be purchased in Belarus is of 300 kECU. The price of such a machine purchased in France would be of 400 kECU which is a similar figure. Using only the annual investment cost based on the Belarus price with an amortisation over a 5 year period and assuming for 12 loggers an averted individual dose of 1,5 $mSv.year^{-1}$ which is the most frequent dose record in 1994 (figure 3), the cost of the averted man sievert roughly evaluated would be of 3,4 MECU. It may be assumed that using a machine may increase the productivity of felling operations and therefore provide an additional benefit.

4.3. Grow saprophyte mushrooms on clean substrate

The agricultural production of mushroom is currently performed and developed, at least, in western Europe. A professional organisation : the European Mushroom Growers' Group is representing the producers of the European Union. So far, the practical application of mushroom culture is mainly concerning saprophyte mushrooms, i.e. mushrooms growing on compost [14-17].

Saprophytes do not constitute a large part of the mushrooms which are naturally growing in Chernobyl forests. Nevertheless, the controlled culture of symbiotic mushrooms is also being investigated, but would suppose to be implemented in not contaminated forests, when saprophyte mushrooms could be grown on artificial substrate inside contaminated areas, therefore avoiding

transport constraints from the production area to contaminated ones. Provided that the populations would adapt their habit to the consumption of new varieties of mushrooms, it may be imagined that off soil mushroom cultures could be organised in forest enterprises in contaminated areas. The mushroom culture necessitates indoors areas which may be available in contaminated areas from the buildings which have been abandoned after the Chernobyl accident. One of the requirements of this culture, which absence sometimes compromises the production under temperate climates, is a sufficient period of cold. This may not be a limiting factor in the CIS.
The cost benefit analysis based on the available economical data shows that for a production cost of mushrooms in France of 3,2 ECU.kg^{-1} and an equivalent of 0,15 averted Man.mSv.y^{-1}.kg^{-1} of mushroom [7], the cost of the averted man sievert would be of 21 kECU. However, it must be stressed that French costs do not satisfy CIS economical comparison. It is likely that this cost could be divided by 5 to 10 to be realistic, the manpower being a significant part of the total cost. Moreover, it should be noted that an additional benefit may be obtained through the economical valorisation of the production of mushrooms, as far as the technique of production would be introduced in the area.

4.4. Valorisation of contaminated wood

This countermeasure is expected to help for mitigating the problem of compliance with permissible levels of ^{137}Cs in wood as well as the problem of the economical burden related to the loss of contaminated wood. So far three options are likely to suit the use of contaminated wood : to burn it in incinerators equipped of a smoke filtration and a contaminated ash removal system, to convert it into paper pulp or into chemicals such as technical alcohol. The incineration may produce energy but the requirements for an economically competitive energy is to care of the availability of fuel as well as the quantity and the form under which the energy can be used. Pulp factories satisfy these requirements in that about 30% of the wood which comes in the plant goes to waste and the need for steam to recycle the chemical reagents is very important.

The decontamination factor (Df) of wood transformed into pulp can be defined by the equation 2

$$\text{Equation 2 : } Df = \frac{\text{Activity of raw wood}}{\text{Activity of the wood derivative}}$$

The Df observed at the industrial scale in Sweden was of about 3 and 58-125 for the acidic process and the alkaline one respectively [13]. These records show that the acidic process is less efficient in decontaminating the wood than the alkaline one. However, is was observed in laboratory experiments performed in the framework of the ECP/4 project that the acidic treatment may be able to achieve a Df of up to 90 [18]. This infers that the pH of the treatment may not be the cause of the different efficiencies of the two processes, but the technology itself.

From the above technical description, it is appearing that pulp factories are pivotal structures for the development of a strategy based on the valorisation of wood capable of providing an economical benefit which may help in the implementation of countermeasures for contaminated forests. But the justification of this countermeasure on the sole basis of a probable benefit in terms of dose reduction, by avoiding the discharge in the environment of radionuclides from

wood waste, would necessitate an exhaustive study which results may be affected of large uncertainties, and may not lead to such an evident issue than the need for improving the economy of Chernobyl affected areas.

The production of technical alcohol from contaminated wood may also be one of the possible options to valorise the production of contaminated forests. So far this way has not been thoroughly investigated with respect to contaminated forests. The possibility of producing ethanol from wood to substitute gasoline has been investigated namely in France during the years of petrol crisis. The way involving the enzymatic digestion of cellulose to liberate simple sugars was proven to be more efficient than the chemical one. However, the ethanol was produced at a higher cost than petrol gasoline. But in the peculiar context of energy dependence combined with the need for contaminated forest management, which is at least the case of Belarus, such option could be re-examined.

4.5. Removal of contaminated litter

This option has been studied in the framework of the ECP/4 project on the basis of a field experiment and by other authors as the application of a model of contaminated forest management [19]. The latter study concluded that about ten years after the deposition of radionuclides, the efficiency of removing the litter is questionable. Indeed the direct observation during the field experiment carried out in 1994 in Belarus showed that a significant part of ^{137}Cs is associated with the fine fraction of organic matter still incorporated into the mineral fraction of the soil. It is therefore necessary to remove a part of the mineral soil to achieve a significant decontamination factor. The rotating brush which was tested proved to be of promising issue, but some adaptation are necessary to the existing equipment, namely the independent depth setting of the rotary brush and its rotation speed.

It is unrealistic to think that the litter can be removed on the thousand of km^2 of contaminated forest. However, in some cases such as clear felling operations or the restoration of some high value recreational forest these operations may be undertaken on limited areas. The evaluation of the benefit in terms of dose reduction is difficult to calculate since it is strongly dependant of the practical case of application. One example is given in the case studies performed within the ECP/4 project : the decontamination of the forested area of Karchovka in Russia, close to the city of Novozybkov, Briansk province. This recreational area was very often visited by people before the Chernobyl accident. Using a quite low dose reduction factor of 2 when removing the litter using a rotating brush, the calculated averted dose was of 0,1534 Man.sievert and the subsequent cost of the averted Man sievert was of 3316 ECU. The transport of the 230 m^3 of generated waste was not included in the cost.
Other examples of application may be given, but cannot be presented without an exhaustive sustaining discussion which is beyond the scope of the present paper.

4.6. Reforestation of agricultural land.

This option may have some connection to the option of litter removal in forest which purpose may be to transform forest areas in agricultural land after decontamination, especially for areas

where sufficient clean pastures are not available. On the opposite, agricultural land which are not any more suitable for agriculture may be reforested. A technique for planting trees in contaminated areas has been developed by the Belarus Institute of Forestry. The interest of this option is to both increase the productivity of an operation of tree planting, relatively to hand made planting, and to decrease the dose for workers. However, although the reforestation option being supposedly applied in heavily contaminated areas, i.e. above 40 $Ci.km^{-2}$, the dosimetric cost is likely to be negligible. The benefit of this option cannot be expressed in terms of dose reduction, but only in terms of economical benefit.

4.7. Decontamination of forest pastures

This option has been investigated in the framework of the ECP/4 project for decontaminating permanent pastures. As mentioned in the above chapter on the problems to be solved, it is likely that the losses of forest pastures represent a large part of the total economical burden. On the other hand, leaving private cows to graze on forest pastures is reported to have a significant contribution to the dose [4]. The cost benefit analysis of the use of a turf harvester for decontaminating permanent pastures may be applied to forest pasture, using only the existing small turf harvesters which are capable of operating in complicated conditions of soil topography [20]. The cost of the averted man sievert was of about 80 ECU.

Table 2 : options for the management of contaminated forests

Option	Aim	Cost of the averted man sievert (kECU)	Economical benefit
Standing tree monitoring	Avoid doses, decrease wood losses	nd	mainly
Tree felling machines	Avoid doses for loggers	3400	yes
Mushroom culture	Avoid internal doses	21♣	yes
Valorisation of contaminated wood	Mitigate economical burden	nd	mainly
Litter removal	Avoid external doses	3,32	yes
Reforestation	Use of contaminated land	nd	mainly
Decontamination of pastures	Avoid internal doses	0,08	yes

♣ = Based on west European costs.

5. Conclusion

The figures that have been calculated to evaluate the various options are not intended to do more than to give an idea of the range of cost effectiveness. Indeed, it appears that these cost effectiveness are strongly dependant of the practical case to which the countermeasure is foreseen to be applied. For example, the most expensive of the proposed options (table 2) which is the use of a tree felling machine could probably exhibit a lower cost of the averted Man.sievert if used in

very heavily contaminated areas, e.g. at a level of up to 37 $MBq.m^{-2}$ where care felling may be necessary. But one of the major difficulty to carry-out studies on decontamination strategies was to obtain data on case studies, especially with respect to dose distributions. It can be noted that among the various options (table 2), the most cost effective countermeasures is aiming at decreasing the internal dose, but on the other hand, it appeared that data about internal dose was very difficult to collect. Therefore one of the first recommendation would be to organise a systematic monitoring of whole body content of ^{137}Cs of people living in affected areas, and to provide the local health units with a number of whole body counters.
One other important issue is the number of people concerned by the dose intended to be decreased. The contamination of forest lead to the exposure of critical groups of populations such as mushroom pickers and forestry workers, but it is likely that the use of contaminated wood lead to a collective dose for the users of this wood. Moreover, forest industry such as pulp factories may lead to the discharge in the environment of radionuclides which may lead to increase the doses for the concerned populations. Whether these doses have a risk signification is questionable, especially if these doses are added to the Chernobyl background. To answer this question, further radioecological studies are necessary.

Finally it must be stressed that few options are available to decrease the doses, but most of the options are likely to have a positive impact on the economy. In terms of compensation, it seems that all actions leading to revive the local economy and namely forestry activities are likely to be interpreted as remedial actions by the population who is facing in his every day life the decreasing forest economical activities.

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