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ALTERNATIVES OF REFORESTING OIL SHALE OPENCASTS IN ESTONIA

A. LUUD* [(1,2)], M. PENSA [(1,3)]

[(1)] Institute of Ecology,
Department of Northeast Estonia
15 Pargi St., Jõhvi 41537, Estonia

[(2)] Institute of Geography,
Tartu University
46 Vanemuise St., Tartu 51014, Estonia

[(3)] Finnish Forest Research Institute,
P.O. Box 16, FIN-96301 Rovaniemi, Finland

In Estonia, reforestation has been considered to be the most sustainable way of restoring the productivity of land damaged by oil shale mining. As distinct reforestation alternatives give different results, three alternative ways of reforesting oil shale opencasts are compared: natural succession, and planting seedlings of either Scots pine (Pinus sylvestris L.) or black alder (Alnus glutinosa (L.)). For evaluation of these alternatives the emergy concept developed by Howard T. Odum was applied. This allowed estimating the environmental work and economic inputs required for developing total aboveground plant biomass and stocks of commercial wood in 30 year-old forest stands. The cost of total biomass production was lowest in natural stands. Highest public benefit per dollar cost and per dollar value came from naturally recovered stands. Thus, unassisted natural succession causes the lightest load on the environment.

Introduction

The inability of economic models to evaluate services provided by ecosystems is one reason why modern societies are confronted by a complex of environmental problems. Although its weaknesses were pointed out by Schumacher [1] and Henderson [2] in the 1970s already, classical economic theory still prevails in our everyday thinking. However, at the end of the 20th century, forced by the increasing ecological crisis, the accounting of environmental inputs to the economic system developed as “ecological economics”, which attempts to combine free environmental services and the

* Corresponding author: e-mail *aarne@ut.ee*

economic system [3]. One possibility is to assign monetary value to ecosystems [4], another is developed by Odum [5, 6] and is based on emergy flows in both economic systems and ecosystems.

Emergy is the universal measure of work being done by the environment as well as by people and is not subject to the relations of demand and supply in the markets [7]. The concept of emergy accounting enables choices to be made between different economic and environmental alternatives. This concept is based on the hierarchy of different kinds of energy. One joule of one kind of energy is not equivalent in its ability to do work to one joule of energy of another kind. Transforming all types of energy to one type, one can estimate the work done by the environment as well as by society or the economy. Emergy is a measure of the available energy of one kind that has previously used up directly and indirectly to make a goods item or service [5, 6]. Sometimes, emergy has been referred as "energy memory" [8].

In Estonia, reforestation has been considered to be the most sustainable way of restoring the productivity of land damaged by oil shale mining, despite the great expense of surface planing and tree planting, which indirectly increases environmental load. However, natural vegetation recovers the disused area without any additional economic input.

After the end of mining, according to the recent practice, the surface of the worked area is planed and trees are planted. The preferred tree species for reforestation is Scots pine (*Pinus sylvestris* L.), but a total of 52 different tree species have been experimentally planted [9]. The productivity of planted stands tends to be better than that of the original stands before mining [10]. The most productive species are Siberian larch (*Larix sibirica* Led.) and black alder (*Alnus glutinosa* (L.)), but Scots pine is preferred because of its economic importance and availability of planting material. The most prosperous in the naturally recovered stands are silver birch (*Betula pendula* Roth) in tree layer and different willow species (*Salix* sp.) in the understorey [11, 12].

In this paper three alternative ways of reforesting oil shale opencast mines in respect to their emergy consumption are compared:

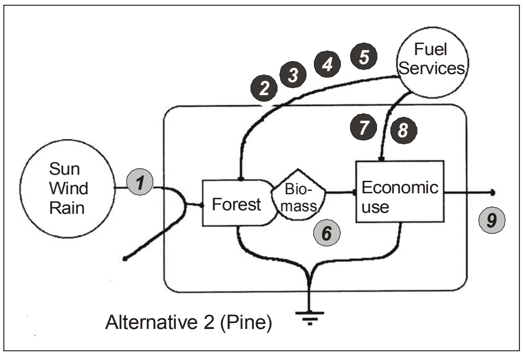
1) natural succession
2) planting seedlings of Scots pine
3) planting seedlings of black alder

The main questions to seek answers to were: 1) whether natural succession would be a more sustainable way of restoring abandoned oil shale opencasts than the planting of trees, and 2) whether tree species affect the sustainability of engineered restoration.

Methods

In June 2002 randomly five (10 × 10)-m sample quadrates in Scots pine, black alder and naturally recovered stands in reforested opencasts were chosen to estimate stand productivity. The average age of the stands, according to the forest inventory data, was thirty years. All trees in each quadrate were counted and their diameters measured for estimating commercial wood and total aboveground biomass. In addition, the biomass of ground vegetation was estimated by cutting and weighing all vascular plants from 0.4×0.5 m randomly chosen plots (five plots per a sample quadrate).

The first procedure for environmental accounting with emergy is diagramming the system to obtain an overview of the flows of energy and resources necessary for creating and maintaining the system (see the Figure as an example for a pine stand).



Energy flows for alternative 2. Numeration is the same as in Table 2 (black circles are energy flows of feedback from higher levels in energy hierarchy)

Clearly the inputs from the environment (input *1* in the Figure) are the same for all three alternatives. However, the inputs from economy differ between natural and planted stands (Table 1). In the next step, all input values are transformed to solar energy equivalents, which is by definition equal to solar emergy value (sej – solar energy joule) (Table 2). Thus, solar emergy is the amount of previously used up solar energy for making a goods item or service. Solar transformity as a measure of the amount of solar emergy per energy unit (sej/J) present in a goods item or service is used for transforming different kinds of energy into the solar one [4].

Also, it is possible to calculate the emergy/money ratios by dividing annual emergy use by the gross national product in the same year. Dividing any particular emergy flow with emergy/money ratio gives us an additional measure – em$ for comparison alternatives in the monetary terms. In this work, emergy production per capita of the Soviet Union in 1980–1987 [4, p. 206] and Estonian gross domestic product in 2002 [13] were used for calculating the emergy/money ratio. Inputs and outputs are considered for a 30-year period (see Table 2).

Table 1. **Cost and Benefits of the Three Alternative Ways of Reclamation per Hectare of Opencast Mine**

	1. "Natural": natural succession on the unplaned surface	2. "Pine": planting seedlings of Scots pine (*Pinus sylvestris* L.) to the planed surface	3. "Alder": planting seedlings of black alder (*Alnus glutinosa* L.) to the planed surface
Planing the surface			
Costs:			
Fuels	–	400 l[a]	
Electricity	–	19,000 kWh[a]	
Services	1 $	1576 $[a]	
Planting the seedlings			
Services	–	171 $	
After 30 years:			
Stands	Birch dominated (55%) mixed stands	Pine stands	Alder stands
Aboveground production	78 t	136 t	216 t
Commercial biomass	55 t	98 t	153 t
Clearcut			
Costs:			
Fuels	7 l/t[b]	6 l/t	
Services	17.5 $/t[b]	15.5 $/t	
Benefits			
Commercial wood prices	39 $/t	71 $/t	45 $/t

[a] Source: A. Lüüde, State company *Eesti Põlevkivi*, personal communication.
[b] The costs were supposed to be 1.5 times higher than regarding the planed surface.

Table 2. **Estimation of Emergy Flows for Alternative 2 "Pine"**

Note No.		Resources, used units (J or $) per ha	Solar emergy per unit (sej/J)[a]	Solar emergy stored (E + 13 sej)	Mean annual solar emergy use (E + 13 sej/yr)
1	Environmental sources: sun, rain, wind, soil			900	30
	Planing:				
2	Fuels	1.42E + 10 J	6.6E + 04	94	3
3	Electricity	6.84E + 10 J	1.6E + 05	1094	37
4	Services	1580 $	4.0E + 12	632	21
5	Silviculture services	170 $	4.0E + 12	68	2
	Total			1888	63
6	Aboveground production (136 t)			2788	93
	Harvesting:				
7	Fuels	1.82E + 10 J	6.6E + 04	120	4
8	Services	1515 $	4.0E + 12	606	20
	Total			726	24
9	Commercial biomass (98 t)	2.08E + 12 J	–	3514	117

[a] Transformities (Odum, 1996); emergy/money ratio: Estonian GDP (2002) 6E + 9 $;
Mean annual emergy consumption in USSR 1980–1987 per capita 16E + 15 sej/yr (Odum, 1996);
Estonian population 1.5E + 6 (emergy/money ratio is 16E + 15 sej/yr*1.5E + 6/6E + 9 $).

Notes (numeration is the same as that of the flows in Fig. 1):

1. Total emergy flow per hectare (Odum, 1996).
2. Secondary planing the spoils with shovel 10 h/ha; fuel consumption 40 l/h; 3.56E7 J/l (fuels = 10 h/ha*40 l/h*3.56E+7 J/l).
3. Primary planing the spoils with dragline 10 h/ha, power of main engine 1900 kW (electricity = 1900 kW*10 h *3600 s/h*1000 W/kW).
4. Services for planing 1580 $/ha.
5. Services for reforestation 170 $/ha.
6. Aboveground biomass 136 t.
7. Fuel consumption for sawing and transporting 5.3 l/t; commercial wood 98 t/ha; available energy 3.56E+7 J/l (fuels = 5.3 l/t* 98 t*3.56E+7 J/l).
8. Commercial wood 98 t/ha; services for harvesting 13 $/t; fuel price 0.5 $/l; fuel consumption for sawing and transporting 5.3 l/t (services = 98 t/ha*(13 $/t + 0.5 $/l*5.3 l/t)).
9. Commercial wood 98 t/ha; available energy 5064 kcal/kg (commercial wood = 98 t/ha *1000 kg/t*5064 kcal/kg*4186 J/kcal).

Results

Several emergy indices characterising economic and environmental load of the alternatives are given in Table 3. Annual cost per biomass unit (row **1** in Table 3) is lower in the case of natural succession due to the absence of economic inputs, and higher in pine stands where production is slower than in the alder stands. Both planted stands have very similar and significant share of the economic load (row **2**). Emergy yield ratio (row **3**) shows how many times more real wealth goes to the economy than received back. The production of natural stands has a two times higher emergy yield ratio and thus gives more real wealth.

Table 3. **Comparison of Alternatives on the Basis of Different Emergy Indices**

Notes[a]		Alternatives		
		1. "Natural"	2. "Pine"	3. "Alder"
1	Total costs, em$/ha/yr/t	0.97	1.70	1.08
2	Share of economic imputs in total costs %	0.04	68	68
3	Emergy yield ratio (harvested biomass)	2.60	1.34	1.30
4	em$/$ cost	2251.00	3.98	3.98
5	em$/$ value	1.03	1.23	1.29

[a] Numerals in the formulas correspond to Table 2 and Fig. 1.
1. (1 + 2 + 3 + 4 + 5)/6 em$/ha/yr/t.
2. (2 + 3 + 4 + 5)/(1 + 2 + 3 + 4 + 5)*100%.
3. (1 + 2 + 3 + 4 + 5 + 7 + 8)sej/(2 + 3 + 4 + 5 + 7 + 8) sej.
4. (1 + 2 + 3 + 4 + 5)em$/(4 + 5)$.
5. (1 + 2 + 3 + 4 + 5)em$/(9)$.

As dollar costs are lower in the spontaneous succession, the emdollar values (em$) per dollar cost (row 4) are higher in natural stands and thus they give more public benefit. In row 5 the potential values of wood were used for calculating ratios of em$/$. This value depends on market prices of timber and diameters of logs. The silver birch dominating in the natural stands has greater economic value than other species at the age of thirty.

Discussion

As the utilization of natural resources continues and opportunities to restore ecosystems damaged by human activities become more common, restoration is playing an increasingly important role in the environment protection [14]. Public opinion mostly has an emotional attitude towards lands degraded by mining activities, and for most people this term includes land that has been left devoid of all topsoil, all vegetation and any hope of regeneration in the short to medium term. The Convention on Biological Diversity signed by most states of the world in Rio de Janeiro in 1992 proposes rehabilitation and ecologically sound restoration of degraded ecosystems as one of the measures to promote the recovery of local biodiversity [15]. Governments have therefore frequently given resources to restore plant cover on degraded lands, believing that this would result in the restoration of the pre-existing ecological state and might add some economic value to degraded lands in the future [16].

The main method of restoration of the Estonian oil shale opencast mining areas is the establishment of Scots pine plantations. The restoration is regulated by the directive of the Ministry of the Environment. The directive sets down that the purpose of restoration should encompass aspects of both economic and ecological importance. However, the studies carried out on the restored oil shale opencast mining areas have mainly focused on questions related to forest management [17, 18]. The outcome of restoration has been measured in the volume increment of growing stock in stands. Except for pedogenesis [10, 12, 19] other ecological aspects of the restoration have rarely been studied in the oil shale opencast mining areas.

Laasimer [11] and Reintam & Kaar [20] have studied spontaneous succession in the oil shale opencasts, but they also put emphasis mainly on the economic outcome, suggesting the establishment of plantations as the only way to achieve a rapid recovering of the mining areas with vegetation. However, if spontaneous succession is undisturbed for decades, valuable ecosystems can develop which may serve as refuges for rare species and communities [21]. The need for comparisons between engineered restoration and spontaneous succession has also been emphasized by Prach *et al*. [14] and Pyšek *et al*. [22].

Our results show that spontaneous succession is the cheapest way of restoring plant cover in oil shale opencasts as it does not need expenses for planing and planting. These works require fuel, electricity and machinery, and their omission makes spontaneous succession the most sustainable method. In the case of spontaneous succession, the vegetation recovers nearly as quickly as in plantations, but its diversity is higher. Silver birch is the dominating tree species (55%) in the natural stands, but the share of other species is also high. In plantations the tree layer is dominated by planted species, which suppress the spread of other trees and form monospecific communities (more than 95% of trees belong to planted species in 30 year-old plantations).

On the other hand, the spontaneously restored forest has lower economic value due to more difficult harvesting conditions and poorer quality of the timber. The surface of opencast spoils is hilly and irregular before planing, with maximum slopes of 20º and differences in heights varying from 10 to 25 m. Forest stands emerge randomly in such areas, trees are of different ages, their stems are often crooked and the canopies are unsteady. The plantations are on a plane surface, their growing conditions are better and less variable. Trees in the stands of the same age are easy to serve and harvest but they are more vulnerable to pest outbreaks and fires.

Market demand and value are important factors in the choice of the tree species for planting. In the opencast spoils, fast growing species of good wood quality, like Scots pine and silver birch, are the most preferable [23]. The forestry industry is also interested in planting different introduced trees, such as larch species (*Larix* sp.), hybrids of poplar (*Populus* sp.), and hybrid aspen (*Populus tremula* L. x *P. tremuloides* Michx.) [24]. Establishment of plantation needs monetary investments, human work and environmental resources, and thus the activity is guided by economic purposes rather than by the need for ecological restoration. Use of introduced species is also at odds with Estonian Forest Law and the Convention on Biological Diversity [15]. A balance between economic interest and sustainable reforestation is attainable by leaving more land to natural succession and by increasing the proportion of alder and mixed stands. More areas could be left unlevelled.

Conclusions

Surface mining of oil shale has an important impact on the environment. Direct influence of mines consists of landscape changes, destruction of local ecosystems and disturbances of the water regime. Indirect impacts are related to oil shale energy production and consumption. The goal of actions to dissolve direct impacts is the restoration of land productivity and ecosystems without increasing indirect environmental effects.

The present research using the emergy accounting method shows that the use of unassisted natural succession is the most sustainable way of reforesting oil shale opencasts. It needs the least inputs, has the lowest ratio of costs to outcomes both on energy and monetary basis, and has the lowest environmental load (indicated by low share of economic inputs in total costs). The diverse tree layer of natural stands creates habitats for wide range of other organisms while plantations tend to stay monospecific for decades.

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REFERENCES

1. *Schumacher, E.F.* Small Is Beautiful. – Blond and Briggs, London, 1973.
2. *Henderson, H.* Creating Alternative Futures. – G.P. Putnam's Sons, Berkley Books, New York, 1978.
3. *Masood, E., Garwin, L.* Costing the Earth: when ecology meets economics // Nature. 1998. Vol. 395. P. 426–430.
4. *Costanza, R., d'Arge, R., de Groot, R., Farber, S. et al.* The value of the world's ecosystem services and natural capital // Nature. 1997. Vol. 387. P. 253–260.
5. *Odum, H.T.* Self-organization, transformity, and information // Science. 1988. Vol. 242. P. 1132–1139.
6. *Odum, H.T.* Environmental Accounting: Emergy and Environmental Decision Making. – John Wiley & Sons Inc., New York, 1996.

7. *Odum, H.T., Brown, M.T., Brandt-Williams, S.* Handbook of Emergy Evaluation. Folio 1: Introduction and Global Budget. – University of Florida, Gainesville, 2000.
8. *Scienceman, D.M.* Energy and emergy // Environmental Economics / G. Pillet, T. Murota (eds.). – Roland Leimgruber, Geneva, 1987. P. 257–276.
9. *Kaar, E., Raid, L.* Some results of reforestation in levelled oil shale surface mines // Metsanduslikud Uurimused (Forestry Studies). 1992. Vol. 25. P. 109–115 [in Estonian].
10. *Reintam, L.* Changes in the texture and exchange properties of skeletal quarry detritus under forest during thirty years // Proc. Estonian Acad. Sci. Biol. Ecol. 2001. Vol. 50. P. 5–13.
11. *Laasimer, L.* Recovery of vegetation in levelled oil shale opencast mines // Metsanduslikud Uurimused (Forestry Studies). 1973. Vol. 10. P. 168–185 [in Estonian].
12. *Reintam, L., Kaar, E.* Development of soils on calcareous quarry detritus of open-pit oil-shale mining during three decades // Proc. Estonian Acad. Sci. Biol. Ecol. 1999. Vol. 48. P. 251–266.
13. http://www.stat.ee/
14. *Prach, K., Bartha, S., Joyce, C.B., Pyšek, P., van Diggelen, R., Wiegleb, G.* The role of spontaneous vegetation succession in ecosystem restoration: A perspective // Applied Vegetation Science. 2001. Vol. 4. P. 111–114.
15. Convention on Biological Diversity, Rio de Janeiro, 1992. http://www.biodiv.org/convention/articles.asp
16. *Hunter, I.R., Hobley, M., Smale, P.* Afforestation of degraded land — pyrrihic victory over economic, social and ecological reality // Ecol. Engineering. 1998. Vol. 10. P. 97–106.
17. *Kaar, E., Lainoja, L., Luik, H., Raid, L., Vaus, M.* Restoration of oil shale opencast mines / Ministry of Forestry and Nature Conservation. – Tallinn, ESSR, 1971 [in Estonian].
18. *Kaar, E.* Coniferous trees on exhausted oil shale opencast mines // Forestry Studies. 2002. Vol. 36. P. 120–125.
19. *Reintam, L., Kaar, E., Rooma, I.* Development of soil organic matter under pine on quarry detritus of open-cast oil-shale mining // Forest Ecology and Management. 2002. Vol. 171. P. 191–198.
20. *Reintam, L., Kaar, E.* Natural and man-made afforestation of sandy-textured quarry detritus of open-cast oil-shale mining // Baltic Forestry. 2002. Vol. 8. P. 57–61.
21. *Kirmer, A., Mahn, E.-G.* Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany // Applied Vegetation Science. 2001. Vol. 4. P. 19–27.
22. *Pyšek, P., Prach, K., Müllerova, J., Joyce, C.* The role of vegetation succession in ecosystem restoration : Introduction // *Ibid*. P. 3–4.
23. *Kaar, E.* Reforestation of oil shale surface mines // Keskkonnatehnika (Environmental Engineering). 2002. No. 2. P. 9–12 [in Estonian].
24. *Pungas, T.* Life-environmenti HASCO projekt (Life-environment's HASCO project) // Keskkonnatehnika. 2002. No. 5. P. 17–19 [in Estonian].

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