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Economic and Ecological Benefits of Reducing Emissions of Sulfur Oxides in the Sostanj Region of Slovenia

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Contents

Acknowledgments iii
Acronyms and Abbreviations iv
Executive Summary 1

Introduction 3
Policies for Reducing Emissions of Sulfur Oxides 3
Forests as Stock and Flow Resources 5
Estimating the Benefits of Reducing Sulfur Oxide Emissions at Sostanj 5
Estimating Timber Values 8
Estimating Non-timber Values 12
Comparing the Costs and Benefits of Reducing Emissions of Sulfur Dioxide from the Sostanj Thermal Power Plant 13
Final Caveat 14

References 15

Technical Annex 17

Text Tables
1. Forest Structure and Value of Output in Sostanj Emission Influence 9
2. Total Economic Value of Reducing Emissions from Unit 5 at Sostanj 13

Text Figures
1. Benefits and Costs of an FGD on Block 5 at Sostanj 2
2. Benefits Valuation of Forests in Area of Sostanj Emission Influence 7
3. Volume of Timber Harvests with and without FGD (cubic meters) 10
4. Nominal (undiscounted) Value of Timber Harvests with and without FGD 10
5. Volume of Trees Standing Stock with and without FGD 11

Annex Tables

A1. With-project Timber Yields, Volume of Standing Stock, and Net Present Values (moder ately damaged forest) 20
A2. With-project Timber Yields, Volume of Standing Stock, and Net Present Values (severly damaged forest) 22
A3. Without Project Timber Yields, Volume of Standing Stock, and Net Present Values (moder ately damaged forest) 24
A4. Without Project Timber Yields, Volume of Standing Stock, and Net Present Values (se verely damaged forest) 26
A5. Growth Functions 28
A6. Volume of Timber Harvests with and without FGD 30
A7. Nominal (undiscounted) Value of Harvests with and without FGD 31
A8. Cumulative Discounted Present Value of Timbner Harvests with and without FGD 32
A9. Incremental Discounted Present Value of Timber Harvests with and without FGD 32
A10. Volume of Tree Standing Stock with and without FGD 33
A11. Nominal (undiscounted) Value and Cumulative NPV of Recreational Benefits 34
A12. Nominal (undiscounted) Value and Cumulative Net Present Value of Non-timber Forest Benefits 35

Annex Figures

A1. Volume of Timber Harvests with and without FGD 30
A2. Nominal (undiscounted) Value of Harvests with and without FGD 31
A3. Cumulative Discounted Present Value of Timber Harvests with and without FGD 32
A4. Volume (undiscounted) Value of Recreational Benefits with and without FGD 33
A5. Nominal (undiscounted) Value of Recreational benefits with and without FGD 34
A6. Nominal (undiscounted) Value of Non-timber Forest Benefits with and without FGD 35

Annex Map

1. Inventory of Forest Decline in Area of Emission Influence from Sostanj 36

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Acronyms and Abbreviations

CVM	Contingent valuation method
DM	German Deutsch Mark
FGD	Flue Gas Desulfurization
IIASA	International Institute for Applied Systems Analysis (Laxenburg, Austria)
MW	Megawatts
NPV	Net present value
PV	Present value
SO_2	Sulfur Dioxide
TEV	Total economic value
US$	United States Dollar(s)

Executive Summary

In preparing the Slovenia Environment Project, the World Bank carried out a study in 1993-94 to evaluate the benefits of reducing sulfur dioxide emissions from Block 5 of the Sostanj Power Plant. Through discussions with forestry and environmental experts in Slovenia, it was determined that the primary damage caused by sulfur dioxide emissions from Sostanj is to the forests which are exposed to high ambient concentrations of sulfur dioxide and to depositions of sulfur in the form of "acid rain." According to the Slovenia Institute of Forest and Wood Economy and others, more than 120,000 hectares of forest have been damaged by emissions of sulfur from the power plant. (Health effects were not identified as an important issue and are not included in this analysis).

Because of concern about forest damage, Slovenia has taken steps that will reduce emissions of sulfur dioxide from Sostanj by about 45 percent from 1991 levels even without installing a flue gas desulfurization unit (FGD) on Unit 5. An FGD installed on Unit 4 and became operation in early 1995. Limestone injection processes are used to limit emissions of sulfur dioxide from Units 1, 2 and 3. The question is therefore: What additional benefit would be possible by reducing emissions further from Block 5 at Sostanj? How much uncertainty is there over these estimates? and, What is the most cost-effective way of reducing sulfur emissions? To answer this question, the analysis considered the impacts on the forest – and the benefits generated by the forest – ***with* and *without*** reducing emissions further from Block 5. The "without project" scenario asks what would be the damages from *not reducing* emissions of sulfur dioxide further. The economic question, simply put, is whether or not the benefits of installing an FGD unit, or using one of the other alternatives, are sufficiently large to justify the expenses entailed.

The approach taken was to consider all the possible benefits from reducing sulfur emissions from Block 5 of Sostanj – timber as well as non-timber benefits such as recreational benefits and watershed protection. Specifically the analysis considered the impacts of sulfur dioxide emissions on (i) timber yields; (ii) forest recreation and tourism; (iii) non-timber forest products such as mushrooms, berries, and meat from game, biodiversity and soil conservation; and (iv) existence and option values which reflect what society is willing to pay to maintain the forest in a natural state for current and future generations.

The analysis looked at how these values would change over a period of 70 years – timber output, recreation and tourism, non-timber forest products, and existence and option values – *with* and *without* a project which would reduce sulfur emissions from Sostanj. Under the *without* project case, emissions would continue unabated from the power plant until its scheduled closing in 2020. Under the *with* project case, emissions from Block 5 would drop to 10 percent of 1991 levels starting in the year 1996 when a flue gas desulfurization unit (FGD) – the proposed investment for controlling emissions of sulfur dioxide – could become operational.

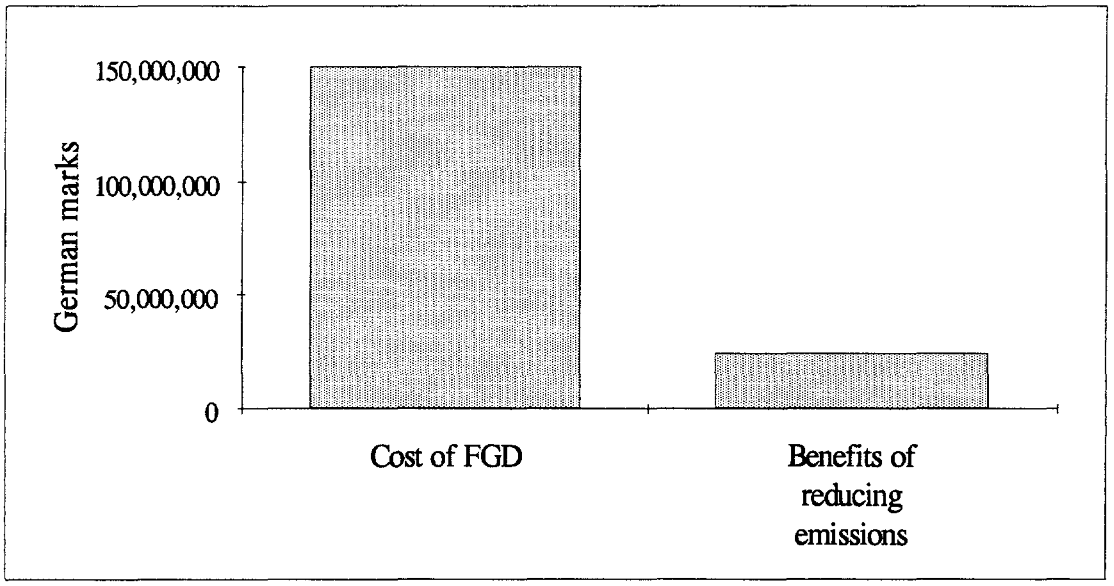
The analysis found that the benefits from reducing emissions to be substantial – with a discounted present value of about 24 million

German marks. However, the FGD costs between 140 and 160 million German marks — more than 115 million German marks higher than the identifiable benefits. Investing in this technology places the country in danger of wasting 115 million German marks, money which could be used for alternative environmental and forestry investments providing higher benefits.

The differences between costs and benefits is clearly seen if we compare the annual costs of the FGD with the annual benefits it is expected to generate. The annualized costs of the FGD are about 17.5 million German marks, comprised of 7 million German marks of capital recovery per year (150 million depreciated over a period of 20 years), and 10 million per year in operating and maintenance costs (including the costs of electricity, limestone, waste disposal, and maintenance for the equipment). The annualized value of all non-timber benefits is about 4 million German marks. Therefore, the project produces annual benefits of about 4 million German marks for a cost of about 24 million German marks per year.

This does not mean that reducing sulfur emissions is not a good idea. Lower-cost measures may well be worthwhile. However the FGD is an extremely expensive solution, whose costs greatly exceed the benefits gained from reducing sulfur emissions.

Figure 1
Benefits and Costs of an FGD on Block 5 at Sostanj
(present value, discount rate = 7%)



Economic and Ecological Benefits of Reducing Emissions of Sulfur Oxides in the Sostanj Region of Sostanj

Introduction

Slovenia is committed to lowering its emissions of sulfur oxides to reduce forest damage, to improve local health conditions and to comply with the proposals to reduce emissions of sulfur oxides in Europe of the United Nations - Economic Commission for Europe. About 76 percent of sulfur oxide emissions in Slovenia in 1991 came from thermal power plants burning coal.

At present, out of a total installed capacity of about 2,000 MW, thermal sources account for almost half of the total power output (hydro provides about 700 MW and the nuclear facility shared with Croatia provides 337 MW of power to Slovenia). The largest thermal facility by far is the Sostanj Thermal Power Plant near Velenje, with an installed capacity rated as between 700-745 MW. (The other thermal plants are smaller: Trbovlje has 164 MW from coal and fuel oil; Moste, located in Ljubljana, uses coal to produce 45 MW, and Bretanica use fuel oil to produce 84 MW of power.) Sostanj has 5 units, three small ones installed in 1956 (30 MW), 1957 (30 MW) and 1960 (75 MW), and two large units: Unit 4 installed in 1972 (275 MW), and Unit 5, installed six years later in 1978, rated at 335 MW. As the single largest power source in the country, and the most reliable, Sostanj plays a key role in the national energy grid.

Sostanj and the nearby town of Velenje have a combined population of almost 40,000. The underground lignite mine in Velenje sends almost all of its 4 million tons annual production to the power plant. The mine is a major employer (employing about 5,000 workers) and has reserves adequate for 40 to 60 years at the present rate of production. The power plant employs about 1000 people and a major appliance factory employs from 6-7,000 people. The power plant, the mine and the appliance factory define the urban area.

Although the lignite from the Velenje mine has a relatively low sulfur content (between 1.2 -1.3 percent), it also has a low energy value. The heating value of lignite per ton of lignite is approximately one-half that of good-quality imported hard coal with a sulfur content of 0.5 percent or less. This means that larger quantities of lignite have to be burned to produce an equivalent quantity of electricity, thereby releasing more sulfur dioxide. In fact, of Slovenia's total annual sulfur oxide emissions of about 180,000 tons, almost half (about 80,000 tons) comes from the Sostanj Thermal Power Plant.

Policies for Reducing Emissions of Sulfur Oxides

A major impetus within Slovenia to address emissions at Sostanj comes from the local effects of sulfur dioxide exposures, particularly on the forests in the Saleska valley, where the power plant is located. Given the particular topography and meteorology of the Saleska valley, the emissions of sulfur dioxide from the power plant have led to localized forest damage, especially at higher elevations. This damage was first noted in specific cases of "scorching" of spruce forests in the winters of

1984/85 and 1986/87.

An additional, but largely unstudied and unknown factor, is the impact of longer term and long range acid deposition from power plant emissions. The tall stacks and prevailing winds mean that sulfur oxide emissions tend to be dispersed (when there is not a thermal inversion) to the north and northeast. A 1990 survey of standing volume and forest condition of forests in Slovenia noted damage to silver fir, a species especially vulnerable to sulfur dioxide exposure, in areas to the northwest, north and northeast of Sostanj, possibly due to sulfur oxide emissions from Sostanj. The full impact on these depositions on the forests and the acidic soils found in this area is still unknown, but adds an important element of uncertainty to the entire equation.

To protect its forests and prevent other types of damage attributed to exposure to sulfur oxides, Slovenia is eager to reduce sulfur oxide emissions from Sostanj. A flue-gas desulfurization unit (FGD) installed on Unit 4 at the power plant became operational in early 1995. Emissions from all other Units, including Unit 5, are being reduced with limestone injection processes. Together these steps have reduced sulfur oxide emissions from the power plant by about 45 percent from 1991 levels, by 1995. To further reduce emissions from the power plant, it will be necessary to address emissions from Unit 5. For this, Slovenia has a number of options:

1. Install an FGD unit on Unit 5.
2. Change the source of coal to imported, low sulfur coal.
3. Change the operating rules at Unit 5 to minimize sulfur oxide emissions during periods of atmospheric inversion, thereby limiting forest damage from direct exposure (taking into account the effects of reducing sulfur oxide emissions from the FGD unit which became operation in early 1995 on Unit 4.
4. Shut down Unit 5 or replace it with a gas-fired plant.
5. Install a gas turbine on Unit 5 for use during periods of temperature inversions.
6. And finally, an option that addresses the forestry issues but not the sulfur oxide emissions is to increase the proportions of beech or other pollution-tolerant species in the forest area. Beech traditionally comprised more than 50 percent of the trees in the forests of this area and is potentially as commercially valuable as spruce.

Each of these six options has various costs associated with it. The major economic costs are the following:

1. An FGD unit will cost from 140-160 million German marks (about, US$90-100 million[1]).
2. Importing coal will require investments in infrastructure to transport the coal to Sostanj.
3. Reducing electricity output may be unacceptable during periods of peak demand.
4. Replacing the electricity from Unit 5 will require investments in new generating capacity.
5. The economics of adding a gas turbine to Unit 5 have to be examined in more detail.
6. Converting the surrounding forest to beech will take many decades under Slovenia's current forest management regime.

Some of these options (particularly 2 and 4) will result in job losses at the coal mine in Velenje.

Unit 4 has already been fitted with an FGD unit which reduced sulfur oxide emissions from Sostanj considerably starting in 1995. The question is: How large are the potential benefits from additional reductions in sulfur oxide emissions from Unit 5? How much uncertainty is there over these estimates? and, What is the most cost-effective way of reducing sulfur oxide emissions? This analysis is framed in a "with and without" framework where the "with project case" is the installation of an FGD unit. (Other means can also be considered for

[1] All values in this paper are computed using mid-1994 exchange rates. For example, 1US$ = 1.6 German marks

reducing sulfur oxide emissions as described above. However, the focus in this analysis is on estimating the *benefits* of reducing sulfur oxide emissions, not on *how* to reduce them.) The "without project" scenario asks what would be the damages from *not reducing* emissions of sulfur oxides. Throughout the analysis we take as a given the current forest management regime practiced in Slovenia.

Forests as Stock and Flow Resources

The major analytical problem is that forests must be considered as both stock and flow resources: that is, there are values associated with the existence of the forests, and there are other values associated with the periodic removal of part of that stock (e.g. harvesting) and converting that part of the stock into a flow of timber or other forest products. Estimates of both components are needed to assess the total economic benefits provided by the forest.

As *stock resources* represented by the standing volume, forests yield important non-timber benefits, including ecosystem and biodiversity benefits and recreational, landscape and other values that depend on the existence of the forest. Many of these values have the characteristics of *public* or *quasi-public goods*, which means that a given quantity of the good can be enjoyed by more than one consumer without decreasing the amounts enjoyed by other consumers. An example of a pure public good produced by a forest is its *existence value*: the utility consumers derive just knowing the forest exists. Potentially, there is no limit to the number of consumers who can derive this form of satisfaction from the forest. This has important implications when valuing forests and other natural resources, since many people who will never enjoy the benefits of forests directly may none-the-less be willing to contribute to maintain them. Recreation is an example of a quasi-public good, since, in uncongested forest areas, more than one individual can enjoy a recreational outing without detracting from another's experience. Maintaining the stock values has been an important dimension in the historical management of Slovenia's forests.

Forests can also be considered *flow resources*, since forests yield a flow of timber and, in some cases, non-timber forest products. This flow depends on biological processes (e.g. how quickly the trees grow) and on management decisions (e.g. how intensively the forests are managed). The values of the flow and stock aspects are quite different and require different valuation approaches.

Estimating the Benefits of Reducing Sulfur Oxide Emissions at Sostanj

The main benefits of reducing sulfur oxide emissions from Sostanj would be direct and indirect economic benefits, including forestry impacts, recreational and tourism benefits, and other ecosystem values.[2] The rest of this paper assess the potential benefits of reducing sulfur oxide emissions from Sostanj in order to compare them to the costs of reducing emissions. The economic question, simply put, is whether or not the benefits of installing an FGD unit, or using one of the other alternatives, are sufficiently large to justify the expenses entailed.

Total Economic Value Approach

Natural resources are economic assets that provide a flow of goods and services of economic value. These goods and services can be divided into direct-use values such as timber and other non-timber forest products, indirect-

2. Human health damage from exposure to emissions from Sostanj is not a major concern. Air quality in the Saleska Valley where Sostanj is located is better than the national average, with relatively low annual concentrations of sulfur dioxide and particulate matter. This is because the tall stacks emit the sulfur far above the valley floor where most people live, and because homes are heated with energy from the power plant rather than with coal.

use values such as watershed protection, and prevention of soil erosion, and non-use values such as option and existence values. In order to compute the benefits of reducing sulfur oxide emissions, we will adopt a Total Economic Value (TEV) Approach (see Pearce and Warford 1993) in which all three types of goods and services are considered.

The most easily identified direct-use value is that of *forestry products* – primarily the extraction of timber. As described later, this is the most straightforward value to obtain and our estimates are based on the annual yield and the change in stock with and without the FGD. Unfortunately, while the value of timber harvests and changes in timber yields is easy to measure, other direct and indirect use values are harder to quantify. Other direct use goods include *non-timber forest products* such as meat from game, meat, berries and mushrooms and such quasi-public good components as *recreation and tourism.* Important indirect use and non-use values include *watershed protection* (including soil protection) and *biodiversity benefits* and *existence and option values.* To our knowledge, no attempts have been made to estimate these values for the forests of in the Sostanj region or elsewhere in Slovenia.

Timber Benefits

Timber on the stump in the forests near Sostanj ranges in value[3] from 5 to 65 German marks per cubic meter (called stumpage value), depending on the size of the trees harvested (see Table 1).[4] We assume that each hectare in a mature mixed-aged forest is selectively cut once every 10 years. The harvest – which is focused on the largest trees but also involves the removal of some smaller trees – yields an average of about 44 cubic meters wood, and provides a net income of about 1,300 German marks per hectare (about 30 German marks per cubic meter) to the owner per 10-year cutting cycle. Our analysis is for a large forest area, 10 percent of which is cut each year.

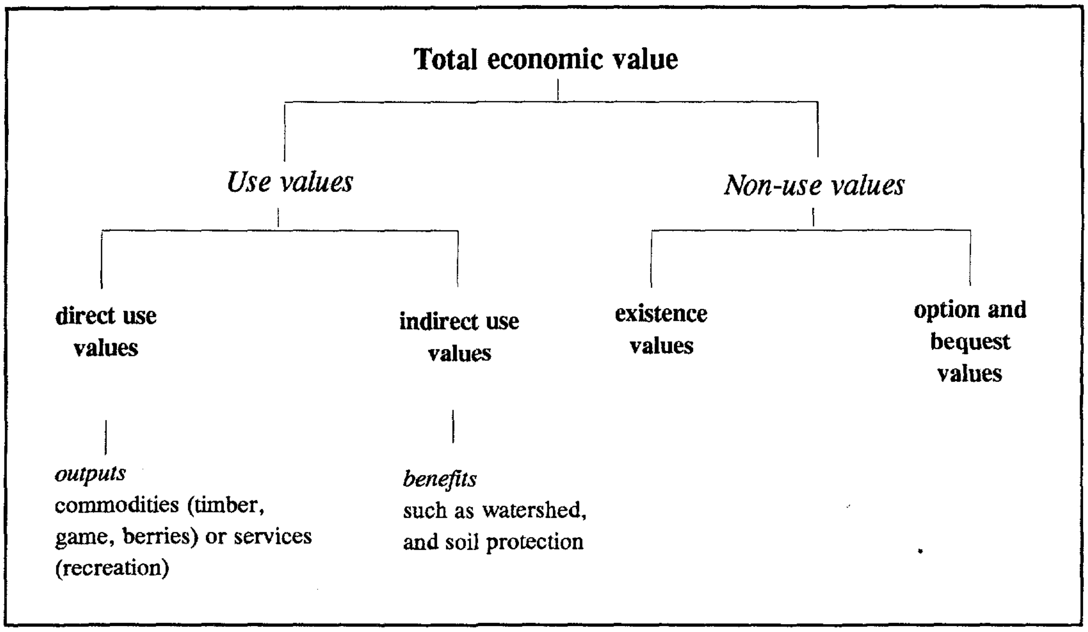
Non-timber Benefits

Unfortunately we have no information about the value of non-timber benefits in Slovenia. We have based our estimates on a survey of a number of papers in the literature that estimated the magnitudes of various non-timber benefits associated with native forests.

Studies done in the United Kingdom estimating the recreational value of Forest Commission lands have found that recreational values are very site-specific, ranging from 3 German marks per hectare per year for forests with little recreational development to 1,400 German marks per hectare per year for forests where public use is exceptionally high. The two most important characteristics distinguishing forests with high recreational benefits from those with lesser recreational value were (a) the location of the forest relative to a population center and (b) the extent of development of its recreational infrastructure. Also important was the age and species composition of the trees: forests yielding the highest recreational benefits had above average proportions of trees in the more mature age classes, with an above-average proportion of broad-leaved trees, while those yielding the fewest recreational benefits are dominated by young spruce or conifers (Willis, 1991). We have adopted a generous value of 100 German marks per hectare per year, slightly less than the annualized value of the timber harvest. The forest lands near Sostanj are currently largely undeveloped for recreation and tourism, so this value is more an indication of future benefits that might be lost if forest loss and dieback become more severe. Without damage, the value of these forests wilderness areas is almost certain to grow with population and income growth and the development of tourist infrastructure. (It should be noted that air pollution from Sostanj has

3. The market value for timber ranges between 70 and 100 German marks per cubic meter. The stumpage value equals the market value less amounts reflecting costs for harvesting, transport, processing, and other expenses.
4. Synthetic but realistic values, based on discussions with Slovenian foresters and with persons involved with forestry operations in other countries of Eastern and Central Europe.

Figure 2
Benefits Valuation of the Forests in the Area of Sostanj Emission Influence



reportedly hurt tourism at the existing hot-springs resort of Topolsica near Sostanj.)

A study measuring the contribution of forestry to the Net National Product in Sweden estimated the values of non-marketed forest products, including firewood, berries, mushrooms, and meat from game to be about 40 German marks net per hectare per year and the benefits of biodiversity and soil conservation to be about 18 German marks net per hectare per year (Hultkrantz, 1992). According to this analysis, non-timber benefits in Sweden thus totaled about 58 German marks per hectare per year. These values were adjusted to account for differences in incomes between the two countries[5] to obtain 18 German marks per hectare per year for mushrooms, berries, meat from game, biodiversity and soil conservation.

Finally, we arbitrarily choose a value of 40 German marks per hectare per year for the non-use benefits, such as existence values. We have no actual information as to how large these values might be in Slovenia, but discussions with government officials and others suggest these are likely to be important.[6]

To calculate the benefits of reducing emissions of sulfur oxides, the analysis considers what happens to both stock and flow variables, (e.g. timber volume and yields, and other forest benefits, such as recreation and protection of watersheds, soils, and biodiversity, and existence values) with and without emissions reductions. The analysis covers a 70-year

5. Slovenia's per capita gross national product is about 25 percent that of Sweden's.

6. Sten Nilsson of IIASA uses an alternative approach to estimate the value of non-timber benefits in a study examining the sustainability of Europe's forests (1992). Using estimates of various direct and indirect use values, he derives a set of multipliers to represent the relative value of non-timber versus timber benefits. The multipiers are then applied to the Net Product Value of wood products to obtain the value of the non-use benefits. For example, if the Net Product Value of wood is 100 units and the multiplier for tourism benefits is 1.32, then tourism benefits are 132 units. Rather than use multipliers, we have chosen plausible *per hectare* values of non-timber benefits from many of the same studies cited by Nilsson.

period, starting with 1996 (when an FGD could be operational if construction started soon), extending to 2020 when the power plant is scheduled to be shut down, and ending in the year 2066, thereby including the recuperation period for damaged forest stocks.[7] In this way the analysis captures the important impacts from sulfur oxide emissions that continue past the closing date of the plant; these impacts are reflected in the differences in forest yields and volume of standing stock under the two scenarios.

The big unknown is the extent of present and future forest damage. The literature on this is mixed: Kolar (1989) cites widespread and extensive damage in his reports while Ferlin (1991, 1992) is more guarded in his analysis. Since sulfur oxide emissions from Sostanj only increased dramatically in the past 20 years, after the installation of Units 4 and 5, there is the possibility of lagged impacts that are not fully evident. In fact, a major concern of some foresters is the potential for a generalized collapse of the system due to both direct exposure to sulfur oxides in the ambient air and in acidic depositions and due to longer term changes in soil chemistry which might interfere with nutrient take up (the area differs from much of the rest of Slovenia in that it contains largely acidic soils that are not as tolerant to acid depositions as are the basic soils found elsewhere in the country).

Estimating Timber Values

The forests affected by emissions from Sostanj are among the most productive in Slovenia. The growing stock in these predominantly spruce forests averages 246 cubic meters per hectare in contrast to the Slovenia average of about 193 cubic meters per hectare. The annual growth increment for these forests is also above average: 6 cubic meters per hectare in contrast to 5 cubic meters per hectare elsewhere in Slovenia. To allow the forests to recover from what is viewed as excessive cutting that took place up until World War II, timber extraction currently removes only about 72 percent of the annual growth increment.

However some of the forests in this area have also been heavily affected by emissions of sulfur oxides from Sostanj. The Forestry Institute of Slovenia estimates that approximately 100,700 hectares of forests have been moderately damaged and 20,700 hectares severely damaged in the area influenced by emissions from Sostanj (see Map 1). The categories are based on the amount of visible damage to foliage, such as yellowing or defoliation or abnormal branching. Forest damage is not directly proportional to exposure to air pollution, but depends on many factors. The most severe damage occurs in older forests and forests with interrupted structure, and in forests growing on sites with shallow soils, wind, little precipitation, or steep slopes. More damage also occurs in forests with a higher proportion of conifers.

Because damaged trees are prematurely harvested, growing stock is lower on damaged hectares, averaging about 200 cubic meters on moderately damaged plots and about 170 on severely damaged hectares. More controversial is whether the annual tree growth increment is also lower in damaged forests and if so, by how much. The annual growth increment in the emission influence area of Sostanj has been increasing since World War II, but it is possible that growth could have been even greater without exposure to sulfur dioxide.

Slovenia's policy is to manage its forests as naturally as possible in order to maintain their recreational and protective functions and their character and appearance. Forests consist of stands of mixed ages and species. Trees are harvested selectively; clear-cutting is prohibited by law. In Slovenia, rotation periods average 120-140 years for Norway spruce, the

7. It does not really matter how sulfur emissions are reduced, only that there either be a general reduction in emissions over the course of the year or that the peak emergency periods be eliminated or greatly reduced.

dominant species. Although outside the scope of this analysis, alternative forest management regimes offer interesting possibilities for increasing direct economic benefits from the forests. In fact, our preliminary analysis indicates that optimal economic rotations may be 60-70 years and that rotations to produce maximum sustainable-yields may be around 100 years.[1]

Because new stock is regenerated naturally, there are few costs for planting and tending young trees with uneven-aged management, the most costly operation in forestry. But because harvesting costs are higher per unit volume of merchantable timber, this management regime works best for producing large trees of expensive high-quality timbers for which the cost of harvesting represents a small part of the final output. Available data from Slovenia and elsewhere in Central and Eastern Europe indicate that wood cut from the largest, most mature trees is 13 times more valuable than wood cut from the youngest age classes.

Damage to trees from emissions (and other causes) interferes with the management regime practiced in Slovenia and raises its costs. Sickly trees must be identified and removed before the quality of their marketable wood deteriorates. Therefore foresters must visit individual plots much more frequently than would otherwise be the case, with consequent increases in silviculture costs. Trees must be harvested regardless of size, so harvesting costs are likely to be higher as a proportion of output than under the ideal management regime.

Table 1 below shows the structure of the forest and the values of a unit of wood in the area affected by emissions from the Sostanj Power Plant. The table describes a theoretical mixed age forest on a per hectare basis: what we would obtain if each hectare in the forest resembled the structure of a large forest area made up of stands of even aged trees.

This analysis considers what happens to the quantity, quality and value of timber harvests with and without emissions controls. We assume that with operation of an FGD on Unit 5 in addition to the operation of an FGD on Unit 4, sulfur oxide emissions from Sostanj will fall by 90 percent from 1991 levels, and forest damage caused by emissions of sulfur oxide will be substantially if not completely eliminated. The forests will be managed and

Table 1
Forest Structure and Value of Output in the Area of Sostanj Emission Influence

Age (years)	Age class	Avg. dbh[1] (cm)	Avg. volume/ tree (m^3)	# of stems per ha	Class vol/ha (m^3)	Basal area per tree (m^2)	Basal area per ha (m^2)	Market value/m^3 (DM)	Stumpage value/m^3 (DM)
0-20	1	< 10	..	..	..	..	..	..	..
20-40	2	12.0	0.12	170	20	0.03	5.0	70	5
40-60	3	17.5	0.30	120	35	0.04	4.5	80	10
60-80	4	25.0	0.60	70	45	0.07	5.0	85	18
80-100	5	32.0	1.00	60	60	0.11	6.5	90	30
100-120	6	41.0	1.40	40	55	0.13	5.0	100	45
120-140	7	> 45	1.60	20	30	0.15	3.0	110	65
Total					**245**		**29**		

1. Diameter at breast height.

Source: Slovenia Institute for Forest and Wood Economy, 1993 harvested as in the past: while small trees will be thinned, cutting will be focused on trees 120-140 years old; harvests will remove only about 72 percent of the period's growth increment and the volume of standing timber per hectare will steadily rise. Over time, the value of the output will rise commensurate with rising yields, especially in the largest diameter classes.

Even without the FGD on Unit 5, emissions from the Sostanj Thermal Power Plant are expected to fall by 45 percent from 1991 levels due to the start-up of the FGD on Unit 4 and to limestone injection on all other Units.

With continued, although reduced, exposure to sulfur dioxide, we assume that tree growth rates are lower and that mortality losses are

Figure 3
Volume of Timber Harvest with and without FGD (m^3)

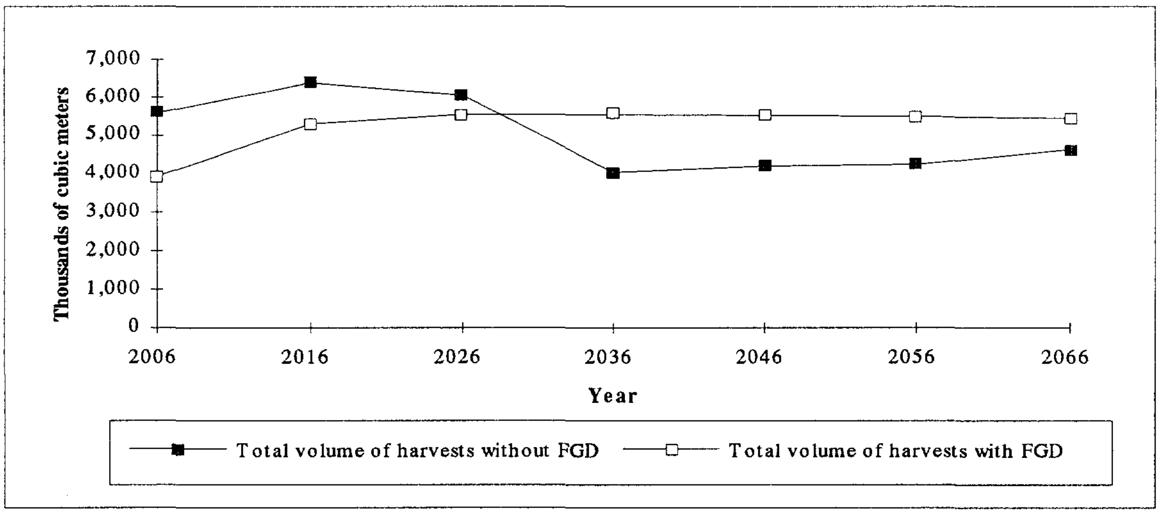


Figure 4
Nominal (undiscounted) Value of Timber Harvests with and without FGD

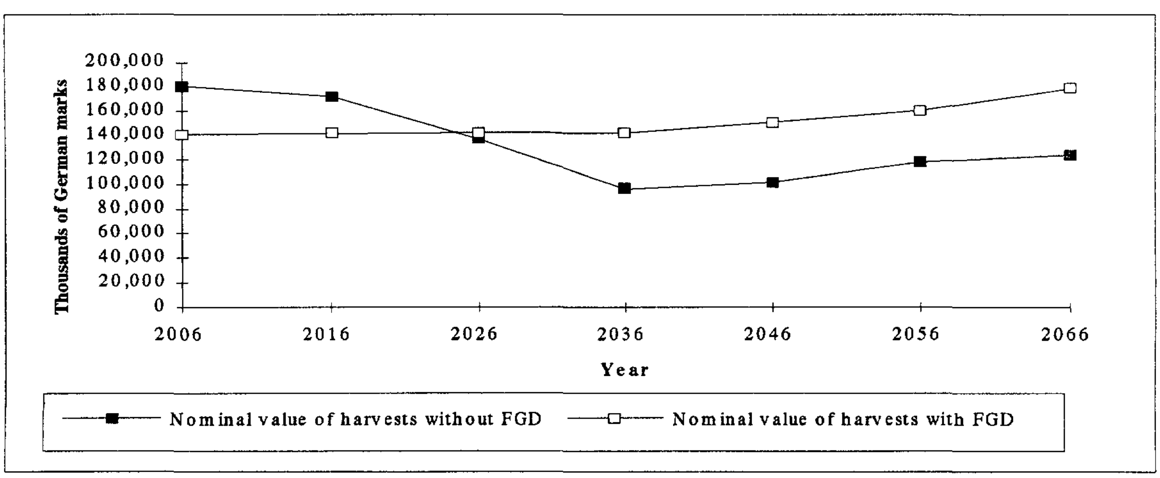
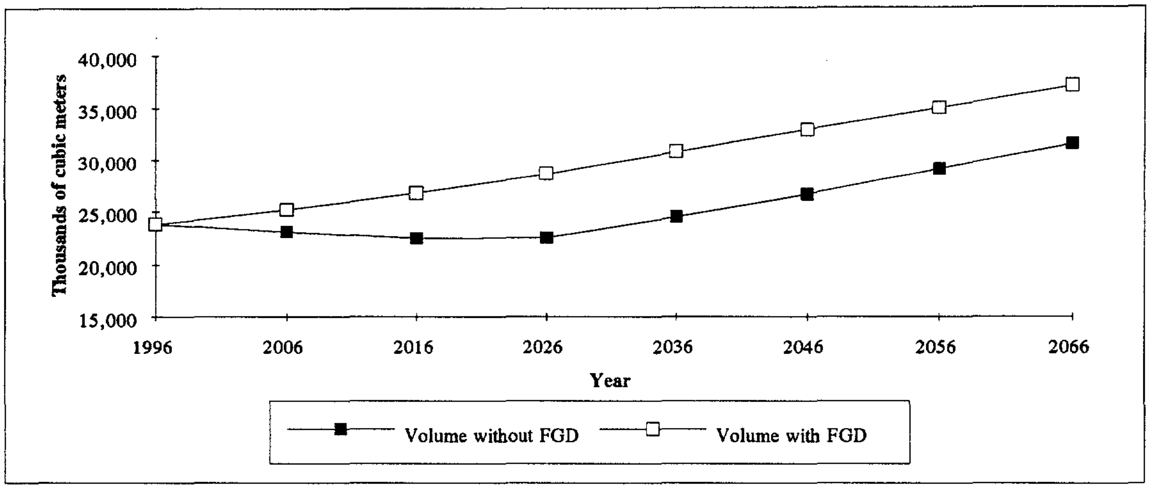


Figure 5
Volume of Tree Standing Stock with and without FGD



higher than they would be with more stringent emissions controls until Unit 5 is shut down in 2020, and continuing for a few years thereafter. Therefore, without emissions controls, the total volume of wood cut greatly exceeds that expected under the ideal management regime between 1996 and about 2026. However the evidence suggests that mortality losses from sulfur oxide emissions are concentrated among the younger, smaller classes and this is the assumption we use here (see Annex Tables A1-A4). This means that the value of the premature harvests is not as great as the difference in harvest volume would imply, since small trees are so much less valuable in the marketplace. Figure 3 shows the volume of timber harvested and Figure 4 shows the nominal values of the timber harvests under the two scenarios from 2006 to 2066. The figures show that harvests are higher without emissions controls than with controls until several years after Unit 5 is closed, and lower thereafter.

Under the "no project" scenario, we assume that silviculture costs are 10 German marks higher per hectare per year than they would be with the project until the time *when* the power plant closes. This further *reduc*es the value of the early harvests.

From 1996 to 2020, the removal of damaged trees means that harvests exceed the annual growth increment on all plots currently considered damaged so that standing volume in 2020 is below 1996 levels. When emissions cease in 2020, annual harvests fall to 65 percent of the annual growth increment to allow the accumulation of biomass. This is below the proportion of growth increment harvested with the project, 72 percent.

Based on data currently available, the present value of timber output from reducing sulfur oxide emissions is approximately negative 7 million German marks, assuming a discount rate of 7 percent. This counter-intuitive result occurs because the total discounted value of the timber harvested without emissions controls exceeds the value with controls until 2020. Therefore, discounting the stream of revenues that will occur with and without the controls indicates very little direct forestry benefit from the investment in the FGD: whenever the discount rate is greater than the forest growth rate (about 2.4 percent per year), the larger timber harvests that occur in the short-term *without* the FGD are more valuable then the higher yields that will occur later *with* the FGD.

However, *without* emissions controls, standing volume per hectare gradually declines until emissions cease with the closure of Unit 5 in 2020, after which the forest begins to recover and the volume of standing stock begins to increase. By 2006, standing volume averages 260 cubic meter per hectare. *With* emissions controls, standing volume steadily rises to about 306 cubic meters per hectare (figure 5). Since the analysis of timber benefits under the two scenarios stops in the year 2066, it is necessary to estimate the value of the timber flows that will occur after that. This value is the discounted present value of the expected future timber flow after the year 2066, or what we would expect someone to pay in 1996 for harvests that will occur after the year 2066. For the forests in the emissions influence area of Sostanj, the value of these expected future timber flows after the year 2066 is 1.7 million German marks higher with the project than without it. This adds 1.7 million German marks to the value of the timber benefits generated with the project, for a total of negative 5.4 million German marks.

Estimating Non-Timber Values

In Slovenia, forested lands provide many benefits besides timber, including recreation, protection of soils, watersheds, and biodiversity, and non-use values. It is not known how the values of the non-timber benefits might shift with the further forest degradation due to exposures to emissions of sulfur oxides. Studies done in the United Kingdom and the United States suggest that visitors to forests for recreation are not particularly sensitive to considerable variations in the condition of the forest in deciding to spend time there. The factors that matter most are how long it takes to travel to the forest and its recreational infrastructure.

It is equally uncertain that volumes of other non-marketed forest products decline with changes in the volume of standing timber. Indeed, many of the non-marketed forest products may well increase with declines in the standing stock, at least with the initial opening of the canopy. For example, deer and other wildlife prefer newly cut forests to dense, old forests. Berries and mushrooms both benefit from light, and often grow more prolifically after trees have been felled.

For this analysis we make the extreme assumption that tourism and recreation and all other non-timber benefits decline in proportion with the decline in the standing stock per hectare. For example, if the volume of standing stock declines by 25 percent – falling for example from 250 cubic meters per hectare to 190 cubic meters per hectare – then the quantity of mushrooms and game and the value of recreational visits and all other non-timber benefits also falls by 25 percent. Thus, if the forest disappears completely (an extremely unlikely event), all non-timber benefits will be lost. Thus the driving factor is the estimate of the values associated with the standing stock with and without reductions in sulfur oxide emissions.

If sulfur oxide emissions continue to damage the forest, the financial *benefits* from earlier harvests of damaged trees are countered by the economic *costs* of lost recreational and tourism services, watershed and other ecosystem values, declines in other non-timber forest products, and reductions in the feeling of well-being associated with the knowledge that the forest is healthy. Based on the values presented earlier – 100 German marks per hectare for tourism and recreation, 18 German marks per hectare for other non-timber forest benefits, and 40 German marks per hectare for existence

8. The maximum sustainable-yield rotation period is at the point in the tree's life cycle when its mean annual growth increment is at a maximum. However, economic efficiency requires harvesting trees at the time which maximizes the present value of the net benefits from the wood. This time occurs when the tree volume growth rate just equals the interest rate. At any positive discount rate, optimal economic rotations will be shorter than rotations where the objective is to maximize sustainable yields. If discount rates are positive, the growth rate of harvested trees must be faster so the trees must be younger; the higher the discount rate, the shorter the optimal economic rotation.

Table 2
Total Economic Value of Reducing Emissions from Unit 5 at Sostanj Thermal Power Plant, 1996-2066
(present value, 1992 German marks, discount rate=7%)

	Present value *with* project that reduces SO_2 emissions by 90% from Unit 5	Present value *without* project that reduces Unit 5 Emissions	Present value of difference (net benefit of project)
Timber products			
Timber harvests	145,600,000	152,600,000	(7,000,000)
Value of difference in volume of growing stock year 2066	1,700,000	________	1,700,000
Subtotal	**147,300,000**	**152,600,000**	**(5,300,000)**
Other forest products			
Mushrooms, berries, meat from game, biodiversity, soil conservation	33,800,000	30,400,000	3,400,000
Quasi-public goods			
Tourism and recreation	187,500,000	169,000,000	18500,000
Pure public goods	75,000,000	67,500,000	7,500,000
Subtotal	**296,300,000**	**266,900,000**	**29,400,000**
TOTAL PRESENT VALUE	**443,600,000**	**419,500,000**	**24,100,000**

and option values – we estimate that a sulfur oxide emissions reduction project generates 29.4 million German marks in non-timber benefits over a 70-year period from 1996 to 2066 at a 7 percent discount rate.

Comparing Costs and Benefits of Reducing Emissions of Sulfur Dioxide from Sostanj Thermal Power Plant

Total Benefits and Costs

Table 2 presents summary data from both the flow and the stock components of forest impacts of sulfur oxide emissions from the Sostanj Thermal Power Plant, based on the available data. The results are for an area of about 121,400 hectares, 100,700 hectares considered moderately damaged, and 20,700 hectares considered severely damaged. The time horizon is 70 years (from 1996 to 2066). Present values are given for a 7 percent discount rate.

At a 7 percent discount rate, reducing sulfur oxide emissions generates substantial benefits – with a discounted present value of about 24.1 million German marks. This is comprised of two components: non-timber forest product benefits of about 29.4 million German marks *with* emissions controls which are offset by a net reduction of 5.3 million German marks in timber benefits.

However, the FGD costs between 140 and 160 million German marks – more than 115 million German marks higher than the identifiable benefits. This is in spite of the fact that we have chosen values for non-timber goods and services that are on the generous, rather than the lower end of available estimates.

Annual Benefits and Costs

The differences between benefits and costs of reducing sulfur oxide emissions using FGD technology are clearly seen by comparing the annual costs of the FGD with the annual benefits it is expected to generate. The annual costs of the FGD are about 17.5 million German marks, comprised of 7.5 million German marks of capital costs (150 million German marks depreciated over a useful lifetime of 20 years), and 10 million per year in operating and maintenance costs (including the costs of electricity, limestone, waste disposal, and maintenance for the equipment). Annual recreational benefits equal about 2.5 million German marks, those of quasi-public goods equal about 0.5 German marks, and those of pure public goods total about 1 million German marks. Thus the annual value of all non-timber benefits totals about 4 million German marks. Therefore, ignoring the financial costs from reduced early harvesting of trees *with* the FGD, the project produces annual benefits of about 4 million German marks compared to an annual cost of about 17.5 million German marks. Based on these preliminary results, the investment in an FGD for Unit 5 of Sostanj is not justified.

Final Caveat

There is some uncertainty about the results, of course. If timber cutting rates were much higher than estimated here due to more extensive forest damage than currently foreseen, lumber prices might fall or some portion of the wood might be wasted because of insufficient processing capacity. In that case, the benefits from the earlier cutting that would occur ***without*** emissions controls would be reduced, and the associated costs — the lost benefits of non-timber forest values — would be larger.

In addition, the analysis has not included watershed impacts or the possibility of a more generalized systems collapse. The yield, stock and growth estimates, are based on the best available information, but may be subject to revision. And, while we know that Slovenians value their forests highly — and indeed regard their protection as a top national priority — there is little information on how much people would be willing to pay to prevent further forest damage from sulfur oxide emissions. Such values could be estimated using a survey-based hypothetical valuation approach (often referred to as contingent valuation method or CVM), but such survey results were not available for this study. However, the value of these potential benefits would have to exceed 115 million German marks to justify the project — almost five times the benefits we have been able to identify so far.

Even if an FGD is not justified on economic grounds, there are other lower-cost measures that could be justified. A full economic analysis of the alternatives has not yet been carried out. Some of these were discussed at the beginning of this note and include changing operating regimes, switching fuels, and changing (over the longer term) the species composition in the affected area. These options would have to be evaluated to see if their expected benefits exceed their costs.

References

Amann, M., S. Nilsson, W. Schopp, and O. Sallnas. 1994. "Impacts on Forestry and Economic Benefits of Sulfur Abatement in the Sostanj Region of Slovenia" (draft). International Institute for Applied Systems Analysis, Laxenburg, Austria.

Batic, F., D. Jurc, J. Kalan, M. Kovac, A. Kralj, and V. Mikulic. 1993. "Impact of Polluted Gases from the Thermal Power Plant in Sostanj, Slovenia, on the Forest Environment: A Brief Expertise on the Cause-Consequence Relationship in Forest Decline." Slovenia Institute for Forest and Wood Economy, Ljubljana, Slovenia.

Bishop, R. and M. Welsh. 1992. "Existence Values in Benefit-Cost Analysis." *Land Economics* 68 (4): 405-417.

Buongiorno, J. and J. K. Gillis. 1987. *Forest Management and Economics.* New York: Macmillan Publishers.

Clutter, J., J. Forston, L. Pienaar, G. Brister, and R. Bailey. 1983. *Timber Management: A Quantitative Approach.* New York: John Wiley and Sons.

Ferlin, F. 1992. "The Impact of Air Pollution on Productivity of Mature Norway Spruce - A Method for the Quantification of Endangerment of Physiological Forest Functions." Department of Forestry, Biotechnical Faculty, Slovenia.

Ferlin, F. 1992. "Some Characteristics of Dieback Phenomena of Norway Spruce and its Growth Response to the Air Pollution Stress. "Department of Forestry, Biotechnical Faculty, Slovenia.

Hultkrantz, L. 1992. "National Account of Timber and Forest Environmental Resources in Sweden." *Environmental and Resource Economics* 2 (3): 283-305.

Kolar, I. 1989. "Spruce Dieback in the Forests of Saleska Valley." Forest Institute, Nazarje, Slovenia.

Leuschner, W. 1990. *Forest Regulation, Harvest Scheduling, and Planning Techniques.* New York: John Wiley and Sons.

Neher, P. 1990. *Natural Resource Economics: Conservation and Exploitation.* Cambridge, U. K.: Cambridge University Press.

Nilsson, S. 1992. *Sustainability of European Forest Resources – A Case Study.* International Institute for Applied Systems Analysis, Laxenburg, Austria.

Pearce, D. and J. Warford. 1993. *World Without End.* New York: Oxford University Press.

Smith, D. 1986. *The Practice of Silviculture.* New York: John Wiley and Sons.

Willis, K. 1991. "Recreational Value of the Forestry Commission Estate in Great Britain." *Scottish Journal of Political Economy* 38 (1): 58-75.

Technical Annex

The Technical Annex contains tables and figures showing the details of the analysis. Tables A1-A4 show the estimated timber yields with and without the project and Table A5 shows the growth functions used in making these estimates. Figures A1-A3 and Tables A6-A9 show the volume and value of timber harvests for the full 121,000 hectares included in the analysis, with and without the project. Figure A4 and Table A10 present the total volume of tree standing stock under the two scenarios. Figures A5-A7 display the nominal (undiscounted) value of recreational benefits, non-timber forest products, and existence values. Tables A11-A13 give the total values, the average per hectare values, and the cumulative net present values for the two scenarios.

How to Read Tables A1-A5

Tables A1-A4 that follow show the current and projected future structure of a hectare of moderately and severely damaged forests in the emission influence area of Sostanj, given for five year intervals. The tables also show projected harvest yields and the net present value of the yield. Tables A1 and A2 show these values for moderately and severely damaged forests respectively for the *with-project* scenario, and Tables A3-A4 show similar values for the *without-project* scenario. All values are presented on a per-hectare basis. This is an uneven-aged forest, comprised of six age classes. Average volume per tree and net value per unit of wood corresponding to each age class are shown below the table headings.

In Table A1 – the *with-project* scenario for moderately damaged forests – The initial distribution of trees in the six age classes is shown for 1996: there are 130 trees in the youngest age class and 18 in the oldest. The class volume of trees in the youngest age class, computed by multiplying the average volume per tree by the number of stems per hectare, is 16 cubic meters per hectare while that of the oldest is 29 cubic meters per hectare. The forest grows according to the equations presented in Table A5. In 2001 the distribution of trees in the six age classes has shifted. New trees have sprouted and some proportion of existing trees in each class has moved into the next age class. Since this forest has not been cut, total volume per hectare increases.

The forest is managed according to the rules described earlier: any one hectare is harvested once every ten years (ten percent of the forest area is harvested annually), only about 72 percent of the volume growth is harvested, and, except for trees being thinned, harvests are focused on trees in the oldest age classes. The forester determines the desired number of trees per class; all trees in excess of this number are cut. As seen in Table A1, in 2006 there are 207 trees in the youngest age class. The forester wants to retain only 180 trees, so cuts 27. The class yield is 3 cubic meters per hectare with a net value of 16 German marks. The harvest which occurs in 2006 across all age classes yields a total of 35 cubic meters per hectare with a net value of 1256 German marks per hectare. Viewed from the perspective of 1996, the discounted net present value of the harvest is 639 German marks assuming a discount rate of 7 percent.

The tables describe this 10-year growth and cutting cycle for a period of 70 years. The net present values shown are cumulative; the further into the future the harvest, the smaller its incremental discounted net present value. (For example, the net present value in 2066 is only about 14 German marks per hectare more than the value in 2056: 1298 German marks versus 1284 German marks.)

The net present value calculations for the *without* project scenario (Tables A3 and A4) include annual silviculture costs of 10 German marks per hectare until 2026, 5 German marks per hectare until 2031, 2 German marks per hectare until 2036, and 0 thereafter. These silviculture costs are not shown on the table, but are included as costs in the net present value calculations.

Table A1
With-Project Timber Yields, Volume of Standing Stock, and Net Present Values 1996-2066 (per hectare)

Moderately Damaged Forest (per hectare over an area of 100,700 hectares)

Age Class	**1**	**2**	**3**	**4**	**5**	**6**	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
							Row totals
year 1996							
number of stems	130	92	54	48	35	18	377
class volume (m3)	16	28	32	48	49	29	201
year 2001							
stock	174	105	65	52	37	18	450
class volume (m3)	21	32	39	52	51	29	223
year 2006							
number of stems	207	125	77	57	38	18	523
class volume (m3)	25	38	46	57	54	29	248
desired number	180	105	66	53	37	10	451
class volume (m3)	22	32	40	53	52	16	214
cut	27	20	11	4	1	8	72
yield (m3)	3	6	6	4	2	13	35
German marks/class	16	60	116	115	85	863	1256
net present value							639
year 2011							
number of stems	216	126	78	58	39	12	529
class volume (m3)	26	38	47	58	55	19	242
year 2016							
number of stems	241	152	92	65	41	13	605
class volume (m3)	29	46	55	65	58	21	274
desired number	190	110	75	59	40	7	481
class volume (m3)	23	33	45	59	56	11	227
cut	51	42	17	6	1	6	124
yield (m3)	6	13	10	6	2	10	47
German marks/class	31	126	185	182	93	641	1257
net present value							963
year 2021							
number of stems	222	133	87	65	42	9	558
class volume (m3)	27	40	52	65	59	15	258
year 2026							
number of stems	242	158	101	73	45	12	631
class volume (m3)	29	48	61	73	64	19	292
desired number	190	115	83	65	44	6	503
class volume (m3)	23	35	50	65	62	10	243
cut	52	43	18	8	1	6	128
yield (m3)	6	13	11	8	2	9	49
German marks/class	31	130	193	230	91	585	1261
net present value							1129

Table A1 (cont'd)

Moderately Damaged Forest (per hectare over an area of 100,700 hectares)

Age class	**1**	**2**	**3**	**4**	**5**	**6**	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 2031							Row totals
number of stems	217	137	94	72	47	9	576
class volume (m3)	26	41	57	72	65	14	275
year 2036							
number of stems	233	161	109	80	50	12	644
class volume (m3)	28	48	65	80	70	19	310
desired number	190	115	92	71	49	6	523
class volume (m3)	23	35	55	71	69	10	262
cut	43	46	17	9	1	6	121
yield (m3)	5	14	10	9	1	9	48
German marks/class	26	138	179	268	65	585	1261
net present value							1213
year 2041							
number of stems	211	137	102	79	52	9	590
class volume (m3)	25	41	61	79	72	15	294
year 2046							
number of stems	222	160	115	87	55	12	652
class volume (m3)	27	48	69	87	77	20	328
desired number	190	115	98	79	54	6	542
class volume (m3)	23	35	59	79	76	10	280
cut	32	45	17	8	1	6	110
yield (m3)	4	14	10	8	2	10	48
German marks/class	19	135	186	251	83	671	1345
net present value							1259
year 2051							
number of stems	206	137	107	87	57	10	604
class volume (m3)	25	41	64	87	80	16	313
year 2056							
number of stems	211	159	120	95	61	13	659
class volume (m3)	25	48	72	95	85	21	347
desired number	185	115	105	87	59	6	557
class volume (m3)	22	35	63	87	83	10	299
cut	26	44	15	8	2	7	102
yield (m3)	3	13	9	8	3	12	48
German marks/class	16	132	158	246	129	761	1441
net present value							1284
year 2061							
number of stems	196	136	113	95	63	10	613
class volume (m3)	23	41	68	95	88	16	331
year 2066							
number of stems	196	156	125	103	67	14	661
class volume (m3)	24	47	75	103	94	23	365
desired number	185	125	110	91	65	6	582
class volume (m3)	22	38	66	91	91	10	317
cut	11	31	15	12	2	8	79
yield (m3)	1	9	9	12	3	13	47
German marks/class	7	93	158	371	115	850	1594
net present value							1298
Value of stock, 2066	**111**	**375**	**1188**	**2730**	**4095**	**624**	9123
PV of stock, 2066							80

Table A2
With-Project Timber Yields, Volume of Standing Stock, and Net Present Values 1996-2066 (per hectare)

Severely Damaged Forest (per hectare over an area of 20,700 hectares)							
Age class	**1**	**2**	**3**	**4**	**5**	**6**	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 1996							Row totals
number of stems	112	78	45	41	30	15	321
class volume (m3)	13	23	27	41	42	24	171
year 2001							
number of stems	149	89	52	42	30	15	377
class volume (m3)	18	27	31	42	42	24	184
year 2006							
number of stems	179	107	59	43	31	15	433
class volume (m3)	21	32	35	43	43	24	199
desired number	165	90	53	41	31	10	390
class volume (m3)	20	27	32	41	43	16	179
cut	14	17	6	2	0	5	43
yield (m3)	2	5	4	2	0	8	20
German marks/class	8	50	65	67	0	494	684
net present value							348
year 2011							
number of stems	195	110	60	43	31	11	450
class volume (m3)	23	33	36	43	44	17	196
year 2016							
number of stems	217	134	70	46	32	11	510
class volume (m3)	26	40	42	46	44	18	216
desired number	175	105	65	43	31	7	426
class volume (m3)	21	32	39	43	43	11	189
cut	42	29	5	3	1	4	84
yield (m3)	5	9	3	3	1	7	27
German marks/class	25	87	55	81	0	462	710
net present value							531
year 2021							
number of stems	202	125	73	47	31	8	486
class volume (m3)	24	38	44	47	44	13	209
year 2026							
number of stems	221	148	83	51	32	9	545
class volume (m3)	26	44	50	51	45	15	232
desired number	180	110	76	48	31	6	451
class volume (m3)	22	33	46	48	43	10	201
cut	41	38	7	3	1	3	94
yield (m3)	5	11	4	3	2	5	31
German marks/class	24	114	80	83	81	353	737
net present value							628

Table A2 (cont.)

Severely Damaged Forest (per hectare over an area of 20,700 hectares)

Age class	1	2	3	4	5	6	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 2031							**Row total**
stock	203	131	83	52	32	7	509
class volume (m3)	24	39	50	52	45	12	223
year 2036							
number of stems	219	153	93	57	34	9	564
class volume (m3)	26	46	56	57	47	14	247
desired number	180	110	85	52	33	6	466
class volume (m3)	22	33	52	52	46	10	214
cut	39	43	8	5	1	3	98
yield (m3)	5	13	5	5	1	4	33
German marks/class	23	129	86	162	44	287	732
net present value							677
year 2041							
number of stems	200	131	91	57	34	8	521
class volume (m3)	24	39	55	57	48	12	235
year 2046							
number of stems	212	152	100	63	36	9	572
class volume (m3)	25	46	60	63	51	15	259
desired number	185	110	90	59	35	6	485
class volume (m3)	22	33	54	59	49	10	227
cut	27	42	10	4	1	3	87
yield (m3)	3	13	6	4	2	5	32
German marks/class	16	127	103	110	74	319	749
net present value							716
year 2051							
number of stems	200	132	95	64	37	8	536
class volume (m3)	24	39	57	64	52	12	249
year 2056							
number of stems	209	153	103	69	39	9	583
class volume (m3)	25	46	62	69	55	15	272
desired number	185	110	93	64	39	6	497
class volume (m3)	22	33	56	64	55	10	239
cut	24	43	10	5	0	3	86
yield (m3)	3	13	6	5	0	5	33
German marks/class	14	130	111	149	0	355	759
net present value							723
year 2061							
number of stems	197	132	98	69	41	8	544
class volume (m3)	24	39	59	69	57	13	261
year 2066							
number of stems	202	153	105	73	43	10	586
class volume (m3)	24	46	63	73	60	16	283
desired number	185	110	97	69	42	6	509
class volume (m3)	22	33	58	69	59	10	251
cut	17	43	8	4	1	4	77
yield (m3)	2	13	5	4	2	6	32
German marks/class	10	128	91	129	74	416	848
net present value							723
Value of Stock, 2066	111	330	1048	2070	2646	624	6829
PV of Stock, 2066							60

Table A3
Without Project Timber Yields, Volume of Standing Stock, and Net Present Values 1996-2066 (per hectare)

Moderately Damaged Forest (per hectare over an area of 100,700 hectares)

Age class	**1**	**2**	**3**	**4**	**5**	**6**	
Volume/tree	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 1996							Row totals
number of stems	130	92	54	48	35	18	377
class volume (m3)	16	28	32	48	49	29	201
year 2001							
number of stems	171	105	63	51	37	18	444
class volume (m3)	20	32	38	51	51	29	221
year 2006							
number of stems	202	125	74	55	38	18	512
class volume (m3)	24	37	44	55	54	29	244
desired number	165	85	61	48	36	9	404
class volume (m3)	20	26	37	48	50	14	195
cut	37	40	13	7	2	9	108
yield (m3)	4	12	8	7	3	15	49
German marks/class	22	119	139	196	152	968	1596
net present value							746
year 2011							
number of stems	204	106	68	52	37	11	478
class volume (m3)	24	32	41	52	52	17	219
year 2016							
number of stems	233	132	78	57	39	12	551
class volume (m3)	28	40	47	57	55	20	245
desired number	155	85	65	48	35	6	394
class volume (m3)	19	26	39	48	49	10	190
cut	78	47	13	9	4	6	157
yield (m3)	9	14	8	9	6	10	56
German marks/class	47	141	140	256	271	651	1505
net present value							1102
year 2021							
number of stems	197	104	71	53	37	8	470
class volume (m3)	24	31	43	53	51	13	215
year 2026							
number of stems	228	129	80	58	39	10	544
class volume (m3)	27	39	48	58	54	16	242
desired number	155	78	65	48	37	6	389
class volume (m3)	19	23	39	48	52	10	190
cut	73	51	15	10	2	4	155
yield (m3)	9	15	9	10	3	6	52
German marks/class	44	153	167	294	113	421	1191
net present value							1242

Table A3 (cont.)

Moderately Damaged Forest (per hectare over an area of 100,700 hectares)

Age class	1	2	3	4	5	6	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 2031							Row totals
number of stems	196	98	70	53	38	8	463
class volume (m3)	24	29	42	53	54	13	214
year 2036							
number of stems	227	124	78	58	40	10	536
class volume (m3)	27	37	47	58	56	17	241
desired number	170	90	72	51	40	6	429
class volume (m3)	20	27	43	51	56	10	207
cut	57	34	6	7	0	4	107
yield (m3)	7	10	4	7	0	7	34
German marks/class	34	101	67	197	0	451	850
net present value							1295
year 2041							
number of stems	205	111	78	57	41	9	501
class volume (m3)	25	33	47	57	58	14	233
year 2046							
number of stems	230	137	88	62	43	11	571
class volume (m3)	28	41	53	62	60	17	261
desired number	180	100	80	56	42	7	465
class volume (m3)	22	30	48	56	59	11	226
cut	50	37	8	6	1	4	106
yield (m3)	6	11	5	6	2	6	36
German marks/class	30	110	83	191	70	398	883
net present value							1325
year 2051							
number of stems	209	122	87	62	44	10	534
class volume (m3)	25	37	52	62	61	15	253
year 2056							
number of stems	228	147	97	69	46	12	599
class volume (m3)	27	44	58	69	65	19	282
desired number	190	110	90	64	45	6	505
class volume (m3)	23	33	54	64	63	10	246
cut	38	37	7	5	1	6	94
yield (m3)	5	11	4	5	2	9	36
German marks/class	23	110	77	144	72	613	1040
net present value							1343
year 2061							
number of stems	213	133	97	71	48	9	570
class volume (m3)	26	40	58	71	67	14	276
year 2066							
number of stems	225	157	108	78	51	12	630
class volume (m3)	27	47	65	78	71	19	307
desired number	190	120	95	72	50	6	533
class volume (m3)	23	36	57	72	70	10	267
cut	35	37	13	6	1	6	97
yield (m3)	4	11	8	6	1	9	39
German marks/class	21	110	140	181	49	600	1101
net present value							1353
Value of stock, 2066	114	360	1026	2160	3150	624	7434
PV of stock, 2066							65

Table A4
Without Project Timber Yields, Volume of Standing Stock, and Net Present Values 1996-2066 (per hectare)

Severely Damaged Forest (per hectare over an area of 20,700 hectares)							
Age class	**1**	**2**	**3**	**4**	**5**	**6**	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 1996							Row totals
number of stems	112	78	45	41	30	15	321
class volume (m3)	13	23	27	41	42	24	171
year 2001							
number of stems	149	89	52	42	30	15	377
class volume (m3)	18	27	31	42	42	24	184
year 2006							
number of stems	179	107	59	43	31	15	433
class volume (m3)	21	32	35	43	43	24	199
desired number	140	75	48	40	31	9	343
class volume (m3)	17	23	29	40	43	14	166
cut	39	32	11	3	0	6	90
yield (m3)	5	10	7	3	0	9	33
German marks/class	23	95	119	97	0	598	932
net present value							409
year 2011							
number of stems	176	93	54	41	31	10	404
class volume (m3)	21	28	32	41	43	16	182
year 2016							
number of stems	204	115	61	43	31	11	465
class volume (m3)	24	34	37	43	44	17	200
desired number	175	85	43	38	29	7	377
class volume (m3)	21	26	26	38	41	11	162
cut	29	30	18	5	2	4	88
yield (m3)	3	9	11	5	3	6	38
German marks/class	17	89	197	157	140	389	989
net present value							631
year 2021							
number of stems	208	108	51	39	29	8	444
class volume (m3)	25	32	31	39	41	13	181
year 2026							
number of stems	234	135	62	41	29	9	510
class volume (m3)	28	40	37	41	41	15	202
desired number	180	85	47	38	28	6	384
class volume (m3)	22	26	28	38	39	10	162
cut	54	50	15	3	1	3	126
yield (m3)	7	15	9	3	2	5	40
German marks/class	33	149	159	83	82	320	825
net present value							723

Table A4 (cont.)

Severely Damaged Forest (per hectare over an area of 20,700 hectares)

Age class	1	2	3	4	5	6	
Volume/tree (m3)	**0.12**	**0.3**	**0.6**	**1**	**1.4**	**1.6**	
German marks per m3	**5**	**10**	**18**	**30**	**45**	**65**	
year 2031							Row totals
number of stems	213	109	54	39	28	7	452
class volume (m3)	26	33	33	39	40	12	182
year 2036							
number of stems	238	136	65	42	29	8	518
class volume (m3)	29	41	39	42	40	13	204
desired number	190	90	60	40	29	6	415
class volume (m3)	23	27	36	40	41	10	176
cut	48	46	5	2	0	2	103
yield (m3)	6	14	3	2	0	4	28
German marks/class	29	139	52	55	0	235	509
net present value							753
year 2041							
number of stems	218	115	66	43	29	7	480
class volume (m3)	26	35	40	43	41	12	197
year 2046							
number of stems	239	143	76	47	30	8	543
class volume (m3)	29	43	46	47	42	13	220
desired number	190	105	73	43	29	6	446
class volume (m3)	23	32	44	43	41	10	191
cut	49	38	3	4	1	2	97
yield (m3)	6	11	2	4	2	4	28
German marks/class	29	114	32	117	72	251	615
net present value							774
year 2051							
number of stems	215	128	80	48	30	7	508
class volume (m3)	26	38	48	48	42	12	213
year 2056							
number of stems	232	153	90	53	31	8	567
class volume (m3)	28	46	54	53	44	14	238
desired number	190	110	85	49	30	6	470
class volume (m3)	23	33	51	49	42	10	207
cut	42	43	5	4	1	2	97
yield (m3)	5	13	3	4	2	4	30
German marks/class	25	130	51	118	71	254	649
net present value							785
year 2061							
number of stems	211	133	91	55	31	7	528
class volume (m3)	25	40	55	55	44	12	230
year 2066							
number of stems	223	156	100	61	33	9	582
class volume (m3)	27	47	60	61	47	14	255
desired number	185	110	90	58	33	6	482
class volume (m3)	22	33	54	58	46	10	223
cut	38	46	10	3	0	3	100
yield (m3)	5	14	6	3	0	4	31
German marks/class	23	138	106	77	0	275	619
net present value							791
Value of stock, 2066	111	330	972	1740	2079	624	5856
PV of stock, 2066							51

Table A5
Growth functions

The following functions describe the growth of stands of the six age classes that comprise the Norway spruce forests of the area affected by sulfur dioxide emissions from the Sostanj Thermal Power Plant in Slovenia. Severely damaged stands grow more slowly than moderately damaged stands, especially in the younger age classes. Ingrowth (new stems) is also reduced in the severely damaged stands.

With project

Moderately damaged forests (Table A1)
cl(1)=.86*cl(1)-.043*cl(2)-.16cl(3)-.29*cl(4)-.48*cl(5)-.54cl(6)+115

cl(2)=.2*cl(1)+.86cl(2)
cl(3)=.2*cl(2)+.86*cl(3)
cl(4)=.2*cl(3)+.85*cl(4)
cl(5)=.17*cl(4)+.81*cl(5)
cl(6)=.09*cl(5)+.83*cl(6)

Severely damaged forests (Table A2)
cl(1)=.86*cl(1)-.043*cl(2)-.16cl(3)-.28*cl(4)-.46*cl(5)-.5cl(6)+96

cl(2)=.2*cl(1)+.86cl(2)
cl(3)=.17*cl(2)+.85*cl(3)
cl(4)=.16*cl(3)+.84*cl(4)
cl(5)=.14*cl(4)+.82*cl(5)
cl(6)=.08*cl(5)+.83*cl(6)

Without project

Moderately damaged forests (Table A3)

cl(1)=.86*cl(1)-.043*cl(2)-.16cl(3)-.28*cl(4)-.46*cl(5)-.5cl(6)+110

cl(2)=.2*cl(1)+.86cl(2)
cl(3)=.19*cl(2)+.85*cl(3)
cl(4)=.19*cl(3)+.84*cl(4)
cl(5)=.18*cl(4)+.8*cl(5)
cl(6)=.09*cl(5)+.83*cl(6)

Severely damaged forests (Table A4)
cl(1)=.86*cl(1)-.043*cl(2)-.16cl(3)-.28*cl(4)-.46*cl(5)-.5cl(6)+96
cl(2)=.2*cl(1)+.86cl(2)
cl(3)=.17*cl(2)+.85*cl(3)
cl(4)=.16*cl(3)+.84*cl(4)
cl(5)=.14*cl(4)+.82*cl(5)
cl(6)=.08*cl(5)+.83*cl(6)

How to Read Figures A1-A7 and Tables A6-A12

Figures A1-A3 and Tables A6-A9 show the volume and value (nominal and cumulative discounted) of timber harvests for the full 121,000 hectares included in the analysis, with and without the project. Figure A4 and Table A10 present the total volume of tree standing stock under the two scenarios. We obtain the values for the entire forest area by multiplying the per hectare figures, shown in Tables A1-A4, by the total number of hectares in each damage category. The tables also give average per hectare figures.

Figures A5-A7 display the nominal (undiscounted) value of recreational benefits, non-timber forest products, and existence values. Since these categories of benefits are assumed to vary in direct proportion with the volume of standing stock, the graphs all have the same shape. The tables below the figures (Tables A11-A12) give the total values, the average per hectare values, and the cumulative net present values for the two scenarios.

Figure A1
Volume of Timber Harvests with and without FGD

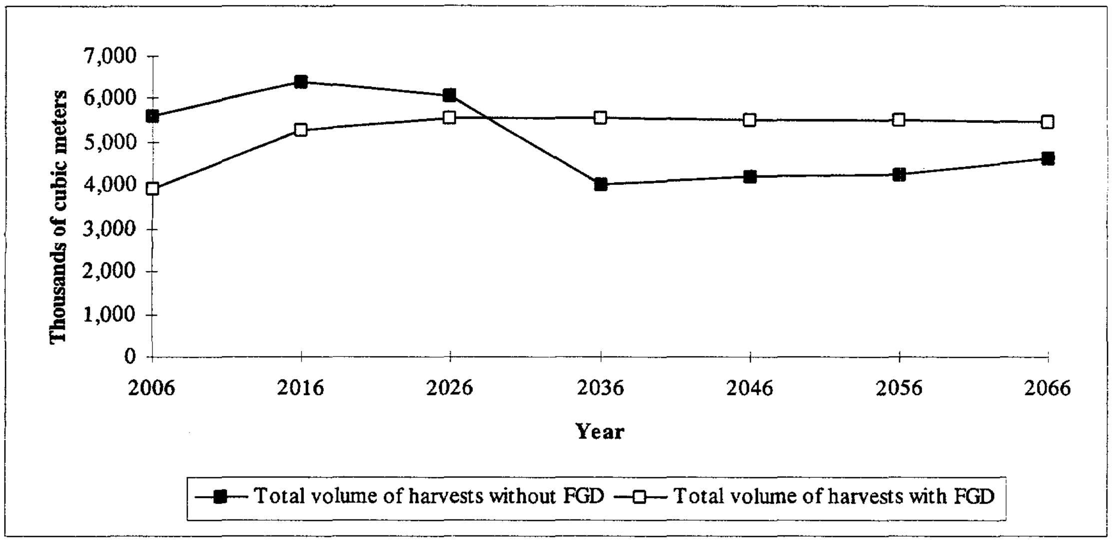


Table A6
Volume of Timber Harvests with and without FGD

	With FGD				*Without FGD*			
	moderate	severe	total	avg per ha	moderate	severe	total	avg per ha
2006	3,502,740	407,632	3,910,372	32	4,916,643	678,461	5,595,104	46
2016	4,729,435	566,370	5,295,805	44	5,617,460	777,451	6,394,911	53
2026	4,899,705	636,998	5,536,703	46	5,240,737	821,192	6,061,929	50
2036	4,859,675	685,123	5,544,798	46	3,443,040	571,205	4,014,245	33
2046	4,850,161	658,471	5,508,632	45	3,597,745	586,832	4,184,577	34
2056	4,816,419	677,477	5,493,897	45	3,601,009	625,498	4,226,507	35
2066	4,773,532	665,243	5,438,774	45	3,962,208	643,590	4,605,798	38

Figure A2
Nominal (undiscounted) Value of Harvests with and without FGD

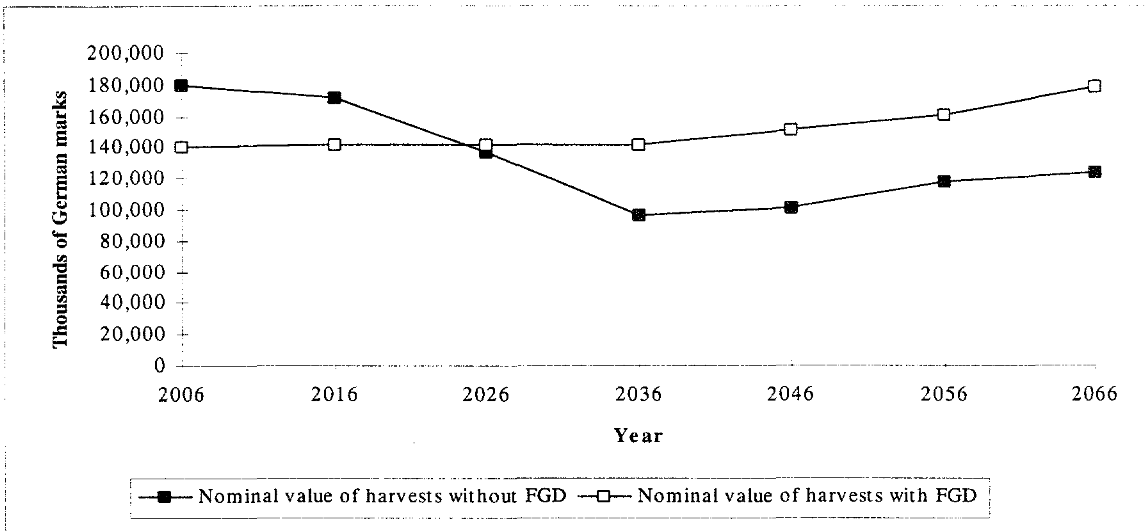


Table A7
Nominal (undiscounted) Value of Harvests with and without FGD (German marks)

	With project moderate	severe	total	avg per ha	*Without project* moderate	severe	total	avg per ha
2006	126,493,141	14,146,241	140,639,383	1,159	160,729,129	19,273,393	180,002,522	1,483,077
2016	126,577,482	14,676,587	141,254,069	1,164	151,559,333	20,446,718	172,006,051	1,417,192
2026	126,998,031	15,236,720	142,234,751	1,172	119,945,775	17,046,136	136,991,912	1,128,704
2036	126,966,944	15,142,225	142,109,169	1,171	85,547,816	10,533,329	96,081,145	791,632
2046	135,387,483	15,492,246	150,879,729	1,243	88,914,557	12,704,534	101,619,090	837,260
2056	145,113,792	15,689,215	160,803,007	1,325	104,686,394	13,421,349	118,107,743	973,113
2066	160,497,335	17,531,458	178,028,793	1,467	110,849,404	12,799,445	123,648,849	1,018,768

Figure A3
Cumulative Discounted Present Value of Timber Harvests with and without FGD

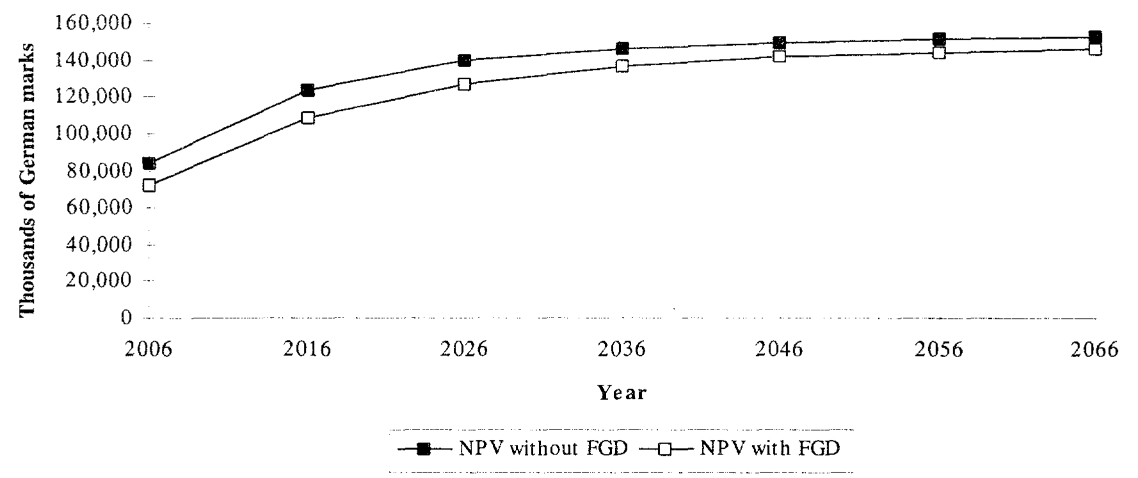


Table A8
Cumulative Discounted Present Value of Timber Harvests with and without FGD

	With project				*Without project*			
	moderate	severe	total	avg/ ha	moderate	severe	total	avg/ ha
2006	64,302,699	7,191,232	71,493,931	589	75,145,895	8,450,657	83,596,552	689
2016	97,012,726	10,983,941	107,996,666	890	110,976,608	13,049,752	124,026,360	1,022
2026	113,696,091	12,985,545	126,681,636	1,044	125,038,144	14,940,974	139,979,118	1,153
2036	122,174,992	13,996,748	136,171,740	1,122	130,415,974	15,575,597	145,991,571	1,203
2046	126,771,094	14,793,429	141,564,523	1,166	133,434,424	16,006,888	149,441,311	1,231
2056	129,275,369	14,947,228	144,222,597	1,188	135,241,030	16,238,504	151,479,534	1,248
2066	130,683,371	14,947,228	145,630,599	1,200	136,213,484	16,350,790	152,564,274	1,257

Note: These present value calculations represent weighted averages over moderately and severely damaged forest areas. The calculations for the without-project scenario include 10 German marks pre hectare per year in silviculture costs.

Table A9
Incremental Discounted Present Value of Timber Harvests with and without FGD

	With project				*Without project*			
	moderate	severe	total	avg/ ha	moderate	severe	total	avg/ ha
2006	64,302,699	7,191,232	71,493,931	589	75,145,895	8,450,657	83,596,552	689
2016	32,710,027	3,792,709	36,502,736	301	35,830,713	4,599,095	40,429,808	333
2026	16,683,365	2,001,604	18,684,969	154	14,061,536	1,891,222	15,952,758	131
2036	8,478,901	1,011,204	9,490,104	78	5,377,830	634,623	6,012,453	50
2046	4,596,102	796,681	5,392,783	44	3,018,450	431,290	3,449,740	28
2056	2,504,275	153,799	2,658,074	22	1,806,607	231,617	2,038,223	17
2066	1,408,002	0	1,408,002	12	972,454	112,286	1,084,740	9

Figure A4
Volume of Tree Standing Stock with and without FGD

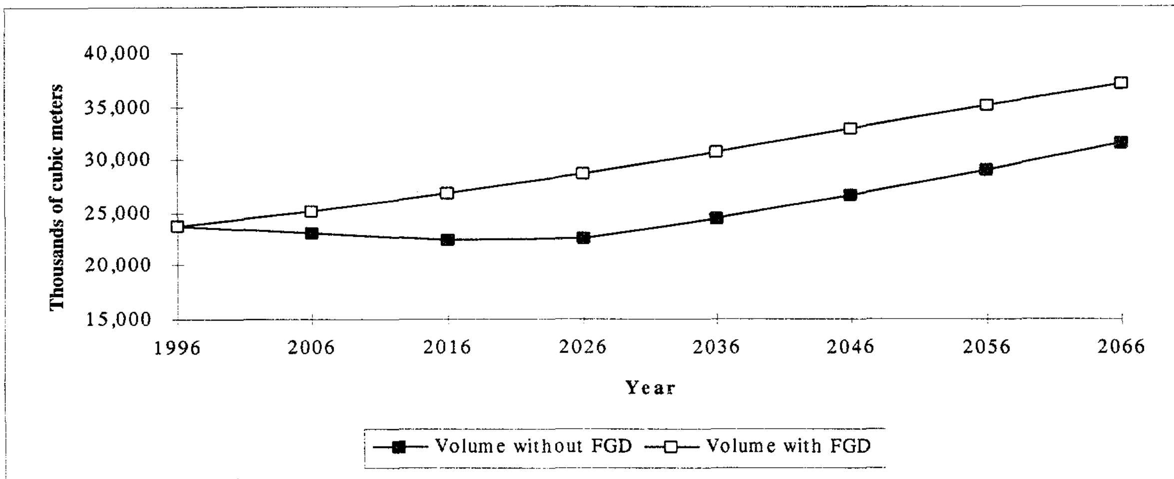


Table A10
Volume of Tree Standing Stock with and without FGD

	With project				*Without project*			
	moderate	**severe**	**total**	**avg/ ha**	**moderate**	**severe**	**total**	**avg/ ha**
1996	20,280,376	3,531,946	23,812,322	196	20,280,376	3,531,946	23,812,322	196
2006	21,498,810	3,700,646	25,199,456	208	19,605,706	3,429,817	23,035,523	190
2016	22,858,219	3,909,453	26,767,672	221	19,102,221	3,351,255	22,453,476	185
2026	24,499,580	4,159,609	28,659,189	236	19,172,709	3,351,255	22,523,964	186
2036	26,352,405	4,432,506	30,784,911	254	20,864,418	3,638,624	24,503,042	202
2046	28,225,369	4,688,863	32,914,232	271	22,717,243	3,954,936	26,672,179	220
2056	30,098,333	4,945,221	35,043,554	289	24,811,741	4,287,788	29,099,528	240
2066	31,951,158	5,185,039	37,136,197	306	26,926,378	4,610,302	31,536,680	260

Figure A5
Nominal (undiscounted) Value of Recreational Benefits with and without FGD

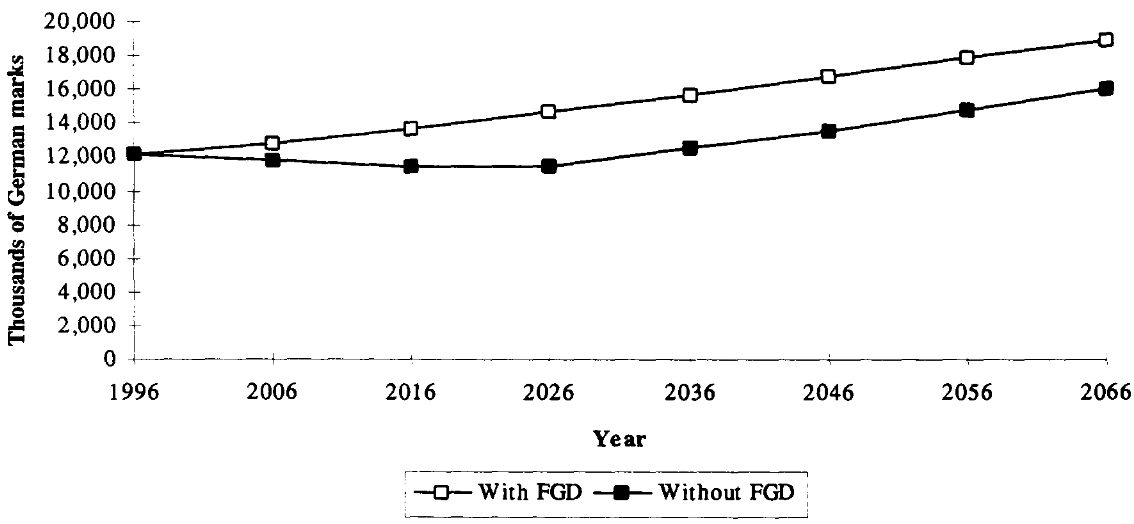
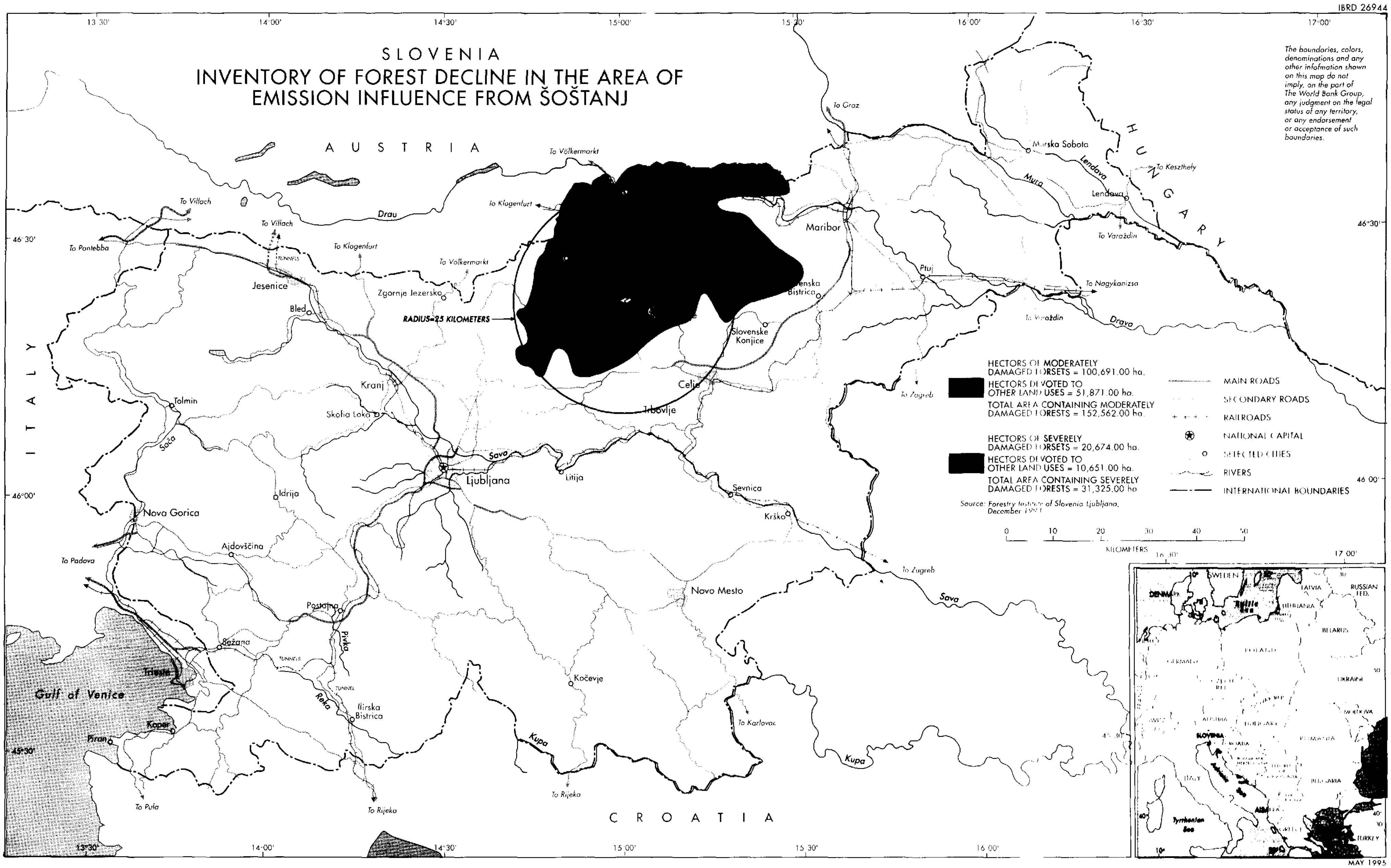


Table A11
Nominal (undiscounted) Value & Cumulative Net Present Value of Recreational Benefits

	With project			*Without project*		
	total nominal	avg per ha	cumulative NPV	total nominal	avg per ha	cumulative NPV
1996	12,137,100	100		12,137,100	100	
2006	12,844,120	106	93,307,604	11,741,167	97	89,726,704
2016	13,643,437	112	137,485,762	11,444,499	94	128,415,621
2026	14,607,540	120	161,437,822	11,480,426	95	147,858,917
2036	15,691,017	129	174,496,101	12,489,159	103	158,188,787
2046	16,776,328	138	181,609,610	13,594,764	112	163,903,153
2056	17,861,640	147	185,467,605	14,831,980	122	167,056,539
2066	18,928,257	156	187,550,708	16,074,192	132	168,806,286



IBRD 26944
SLOVENIA
INVENTORY OF FOREST DECLINE IN THE AREA OF EMISSION INFLUENCE FROM ŠOŠTANJ
The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
AUSTRIA
HUNGARY
ITALY
CROATIA
RADIUS=25 KILOMETERS
Ljubljana
Maribor
Celje
Jesenice
Bled
Kranj
Škofja Loka
Tolmin
Nova Gorica
Ajdovščina
Idrija
Postojna
Sežana
Trieste
Koper
Piran
Gulf of Venice
Ilirska Bistrica
Kočevje
Novo Mesto
Litija
Trbovlje
Sevnica
Krško
Slovenske Konjice
Ptuj
Murska Sobota
Lendava
Zgornje Jezersko
Sava
Drava
Drau
Mura
Kupa
Soča
Reka
Pivka
To Graz
To Völkermarkt
To Klagenfurt
To Villach
To Pontebba
To Keszthely
To Varaždin
To Nagykanizsa
To Zagreb
To Karlovac
To Rijeka
To Pula
To Padova
HECTORS OF MODERATELY DAMAGED FORSETS = 100,691.00 ha.
HECTORS DEVOTED TO OTHER LAND USES = 51,871.00 ha.
TOTAL AREA CONTAINING MODERATELY DAMAGED FORESTS = 152,562.00 ha.
HECTORS OF SEVERELY DAMAGED FORSETS = 20,674.00 ha.
HECTORS DEVOTED TO OTHER LAND USES = 10,651.00 ha.
TOTAL AREA CONTAINING SEVERELY DAMAGED FORESTS = 31,325.00 ha
Source: Forestry Institute of Slovenia Ljubljana, December 1991
MAIN ROADS
SECONDARY ROADS
RAILROADS
NATIONAL CAPITAL
SELECTED CITIES
RIVERS
INTERNATIONAL BOUNDARIES
0 10 20 30 40 50
KILOMETERS
MAY 1995

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The World Bank
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