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'Waldsterben': Our Dying Forests – Part III

Forest dieback: Extent of damages and control strategies

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Summary. This paper starts from the generally accepted premise that forest dieback is a complex phenomenon caused by multiple stresses that are exerted by a host of contributing factors. It is argued that the rapidly proceeding forest dieback, as documented in the damage inventories, is in itself enough reason to warrant action. Therefore, at this late stage, this paper emphasizes the pressing need to introduce active control measures which will reduce pollution emission through more efficient use of fossil fuels, through abatement techniques at the source, and through substitution with less polluting sources.
Key words. Forest dieback; Waldsterben; damage inventory; efficient energy use; abatement techniques; pollution source substitution.

Can we prove the causes of forest dieback?

At first glance the argument that control measures cannot be taken before the causes of forest dieback have been clarified beyond doubt seems enticing. Before this can be achieved, so the reasoning goes, more research will be required to establish a clear linear cause and effect relationship between forest dieback and its likely causes. At a second glance this line of argumentation becomes invalid, since, in principle, such an unequivocal cause and effect relation is not possible in complex and multi-dimensional systems, such as a forest ecosystem. Forest dieback is not the result of a mono-causal but rather of a complex disease caused by multiple stresses[60,69]. The extent to which in each case a specific stress may contribute to damaging a certain tree species at a specified site, could only be verified with sufficient scientific exactitude, if it were possible to carry out, under controlled (laboratory) conditions over a period of several decades, large-scale experiments which would involve, if they were to be realistic, an entire forest[33]. Such an undertaking would be technically and financially unfeasible, and any scientific results emanating therefrom would definitely come too late to halt the rapidly ongoing forest dieback. Moreover, such an experiment would still fail to meet the basic requirement of an experimental scientific proof, i.e. that it could be duplicated any number of times[68].

Forest dieback: Apparition or reality?

With so much scientific uncertainty, can we be sure that a major eco-disaster in the form of forest dieback is on its way? A reasonable approach would be to look around in nature for actual damage and document this by area and over time. The damage could then be traced back, wherever possible, to the various combinations of contributing influencing factors.

Today an observer of forests in Central Europe and elsewhere no longer has any difficulty in finding stands of scrawny firs and sagging spruces, the visible signs of forest dieback. The ongoing damage inventories, as shown below, have documented the various degrees of damage over many years. An important factor contributing to forest damage is acid rain, a term now generally used for the total (dry and wet) atmospheric acid deposition[71]. Acid rain derives, above all, from sulfur dioxide (SO_2) and nitrogen oxides (NO_x) which are emitted into the atmosphere by industrial and transportation as well as commercial and residential sources. In the atmosphere these substances are transformed into sulfuric acid (H_2SO_4) and nitric acid (HNO_3) through oxidation and hydrolysis. The acids and their corresponding sulfates and nitrates are transported through and eventually removed from the atmosphere. The acid deposition leads to the acidification and demineralization of soils, and together with SO_2 and NO_x, it contributes to such adverse effects as damage to forests and agricultural crops, destruction of man-made materials, degradation of drinking water, and, last but not least, impairment of human health. In addition to SO_2, NO_x and acid rain, there is a host of other factors contributing to forest dieback including photochemical oxidants, fluorine, heavy metals, biotic and climatic factors, forest site and forest management, radioactive radiation, and perhaps also electromagnetic waves[17,46,50,53,60].

The role of the scientist and the decision-maker

Because of the many existing uncertainties, scientists, besides calling for further research, usually opt for a 'wait and see' attitude regarding active control measures. The argument is that a few years hence the uncertainties will have been removed so that definitive answers can be given. Such a promise is, of course, quite unscientific. Every researcher knows that further research may in some cases reduce the uncertainties, but it is equally likely to open up new questions which lead to additional uncertainties.

Decision-makers in their daily work are more often than not forced to make far-reaching decisions in the face of much uncertainty. If they wait until they achieve the certainty that will satisfy all critics, it may be too late for countervailing measures. The pivotal question is obviously: How much certainty is enough to warrant action? This question involves a value judgement which has to be viewed against the risks and benefits involved.

In contrast to the carbon dioxide/climate change problem whose likely adverse effects will have to be borne by our progeny, the ongoing forest dieback is quite evident now and the bill for the imminent socio-economic damage will have to be paid by the present generation. It is therefore high time to implement those control measures available now. While in the Federal Republic of Germany (FRG) some politicians and their science advisors realize the urgency of the problem, most of their counterparts in other countries unfortunately have chosen to ignore or belittle the damage.

At this late stage the best strategy seems to be to provide a detailed documentation of forest dieback as a means of pressure for introducing remedial action. This paper reflects this strategy by first presenting an example of a good damage inventory, which is then followed by a detailed discussion of the major control strategies.

Documentation of damage

The impact of air pollutants on plants and animals in the vicinity of industrial sources has been recognized and documented since the 17th century, first in England and Sweden and later in Germany and Austria[14]. But it was only through the tall stack policy, widely adopted during the last two decades, that air pollution and, with it, the acid rain phenomenon has turned into a world-wide problem now affecting large areas not only in Europe[8,15,19,22,25,36,73], North America[6,23,43] and China[29], but also in many remote areas of the world[23], such as Bermuda[35], the North Atlantic Ocean[28] or the Amazon rainforest[27]. Table 1 shows clearly that in earlier years the

Table 1. Development of damaged forest areas in Europe[a]

Year	Area damaged/ha	Remarks	Sources
CSSR			
1960	40,000	Only Erzgebirge	Materna, 1960
1967	250,000–300,000	CSSR	Materna, 1969
Poland			
1961	80,000	Only Upper Silesia of	Sierpinski, 1968
1968	240,000	which 48,000 dead or dying	Sierpinski, 1968
1973	260,000		Paluch, 1973
1980	379,000		Zimny, 1980
GDR			
1960	68,500	By communication	Wentzel, 1967
1965	220,000		Ranft et al.
FRG			
1907	9,000	Smoke damage of which	Reuss, 1907
1960	50,000	31,000 in the Ruhr District	Wentzel, 1960
1982	562,000	National inventories	BML, 1982, 1983, 1984
1983	2549,000		(Ministry of Agric.)
1984	3698,000		

[a] Supplemented and adapted from Wentzel[70], with consent of the publishers.

damaged forest areas in Europe were small and restricted to the vicinity of the industrial areas, while in the past decade or so they have increased greatly in size. Damage is now seen in many remote areas.

The FRG, with a relatively large share of forest land, is not only one of the most severely affected countries, but it has also conducted one of the most detailed damage inventories hitherto. Hence, it can serve as an example of what might be in store for other countries as well. The longest available time series (see fig. 1) shows for 44 test areas the development of the disease status in 556 spruce and 1675 fir trees in Baden-Württemberg over a sequence of eight seasons[59]. The rapidity with which a large percentage of these trees has turned from healthy to sick is quite apparent. While in the fall of 1980 all spruce trees were still healthy, by the spring of 1983 no healthy tree of either species could be found any longer.

The data from a nation-wide inventory for the three years 1982–1984 have been evaluated[12]. Although not entirely comparable because the methods used in 1982 differ from those used in subsequent years, the results do nevertheless indicate that the damage has become more severe and more widespread and now affects all trees in all parts of the FRG. Table 2 indicates that coniferous trees, and above all fir trees, are most severely affected, but that deciduous trees have quickly followed suit. The overall rate has increased sixfold between 1982 and 1984. Table 3 shows that the injured forest area in the FRG has increased more than 7-fold, from about 0.5 million ha in 1982 to 3.7 million ha in 1984. Most severely damaged are

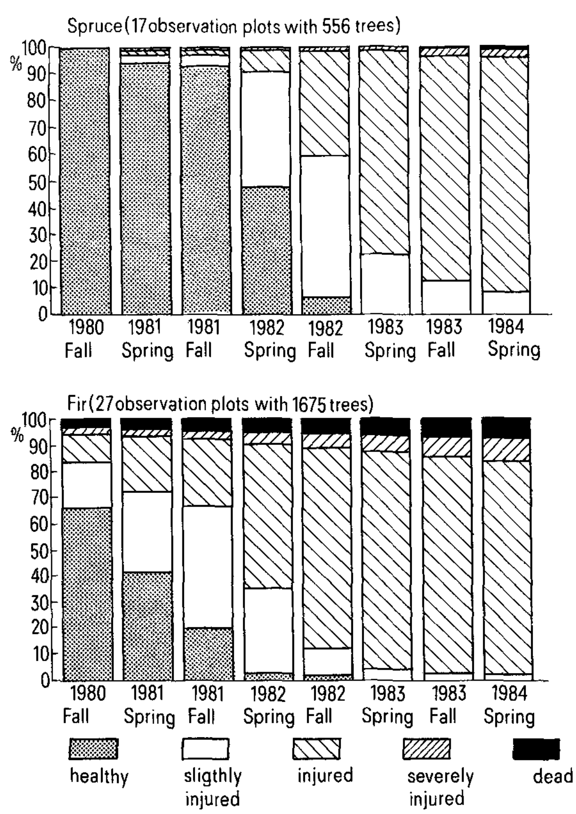

Figure 1. Trend and disease status of fir and spruce trees in Baden-Württemberg. Adapted, with permission from the publishers, from Scheifele[59].

the southern German states ('Länder') of Baden-Württemberg and Bavaria as well as the city states of Hamburg and Berlin, with well over half their forest areas damaged. Finally, the tabulation by severity of injury in table 4 shows that the individual shares within the injury classes have increased from 1982 to 1984 – but not equally. The share and the increase in injury class 'very heavy' remained small, because trees in this category are preferentially cut while they are still of some economic value.

Figure 2 shows an areal and time overview of the FRG forest damage inventories. Two features are apparent: The rapid increase in the percentage of forest area damaged from 1982 to 1984 in all 'Länder' except for Schleswig-Holstein, which used a different sampling procedure in 1982, and the increase in forest damage from north to south. It is reasonable to assume that neighbor-

Table 2. Areal extent of damage by type of tree for 1982, 1983 and 1984 in the Federal Republic of Germany[a]

Type of tree	Total forest area (mill. ha)	1982 Damaged area (mill. ha)	Damaged of total (%)	1983 Damaged area (mill. ha)	Damaged of total (%)	1984 Damaged area (mill. ha)	Damaged of total (%)
Spruce	2.886	0.27	9	1.195	41	1.477	51
Pine	1.470	0.09	5	0.641	44	0.866	59
Fir	0.174	0.10	60	0.135	75	0.152	87
Beech	1.253	0.05	4	0.326	26	0.631	50
Oak	0.620	0.02	4	0.090	15	0.269	43
Other	0.967	0.03	4	0.161	17	0.303	31
Total/av.	7.370	0.56	8	2.549	34	3.698	50

[a] Source: BML[12].

Table 3. Areal extent of damage by federal land for 1982, 1983 and 1984 in the Federal Republic of Germany[a]

	Damaged forest area ($\times 10^3$ ha)			Percent of forested area		
	1982	1983	1984	1982	1983	1984
Schleswig-Holstein	26	16	38	18	12	27
Lower Saxony	124	165	349	13	17	36
Northrine-Westfalia	72	295	358	9	35	42
Hesse	41	120	352	5	14	42
Palatinate	6	180	316	1	23	42
Baden-Württemberg	130	645	862	10	49	66
Bavaria	160	1115	1394	7	46	57
Saarland	3	9	23	4	11	31
Bremen			–			–
Hamburg			2			56
Berlin			4			53
FRG	562	2545	3698	8	34	50

[a] Source: BML[12].

Table 4. Areal extent by severity of damage for 1982, 1983 and 1984 in the Federal Republic of Germany[a]

	Damaged forest area (mill. ha)			Percent of forested area		
	1982	1983	1984	1982	1983	1984
Light	0.419	1.846	2.424	6	25	32.9
Heavy	0.108	0.635	1.163	1.5	8.5	15.8
Very heavy	0.035	0.064	0.111	0.5	0.9	1.5
Total	0.562	2.545	3.698	8	34	50.2

[a] Source: BML[12].

ing countries would have had evidence of similar damage had they conducted comparable inventories. In fact, adopting the FRG sampling method, Luxembourg and Switzerland in 1984 found 16,8% and 34% of their forests damaged, respectively[41,42].
Pollution control legislation at the national and international levels is, at present, woefully ineffective. Without a change of this dismal situation, the trend is a one way street leading from light damage to heavy damage and, in the foreseeable future, to the trees' demise. However, if there were the political will to reverse this trend it could still be done, since technologically feasible, economically affordable, and socially acceptable control strategies are at hand.
These are:
- pollution reduction through more efficient energy use,
- pollution reduction through abatement techniques, and
- pollution reduction through substitution with less polluting sources.

Pollution reduction through more efficient energy use

Presently about 84% of the energy used in the world is from fossil fuels, and this proportion is not likely to change dramatically in the future. Therefore, the more efficiently we use energy, the smaller will be the consumption of fossil fuels, and the lower will be the emission of SO_2, NO_x and a host of other hazardous pollutants. The potential for improving energy efficiency is very large[4,32,39,44,45]. Methodically convincing empirical studies from more than a dozen different countries show through a least-cost energy approach, which implies that people will use energy in a way that saves them money, that in the future, energy needs, and hence fossil fuel use, can be expected to go down, not up[39,40,44,49,55,58,62]. The same or even more energy services can be offered with a lower energy input simply by increasing energy productivity. Without requiring any technological breakthroughs much can be achieved simply by applying present technological know-how in a more rational way. The premise adopted here is that the energy which is saved through more efficient use does not have to be produced and will consequently not contribute to pollution emission. The FRG energy economy may serve as an example to demonstrate the savings potential in the main energy sectors. Since the FRG is already one of the most energy-efficient countries, the potential for efficiency improvements is even larger in most other countries[2,44].

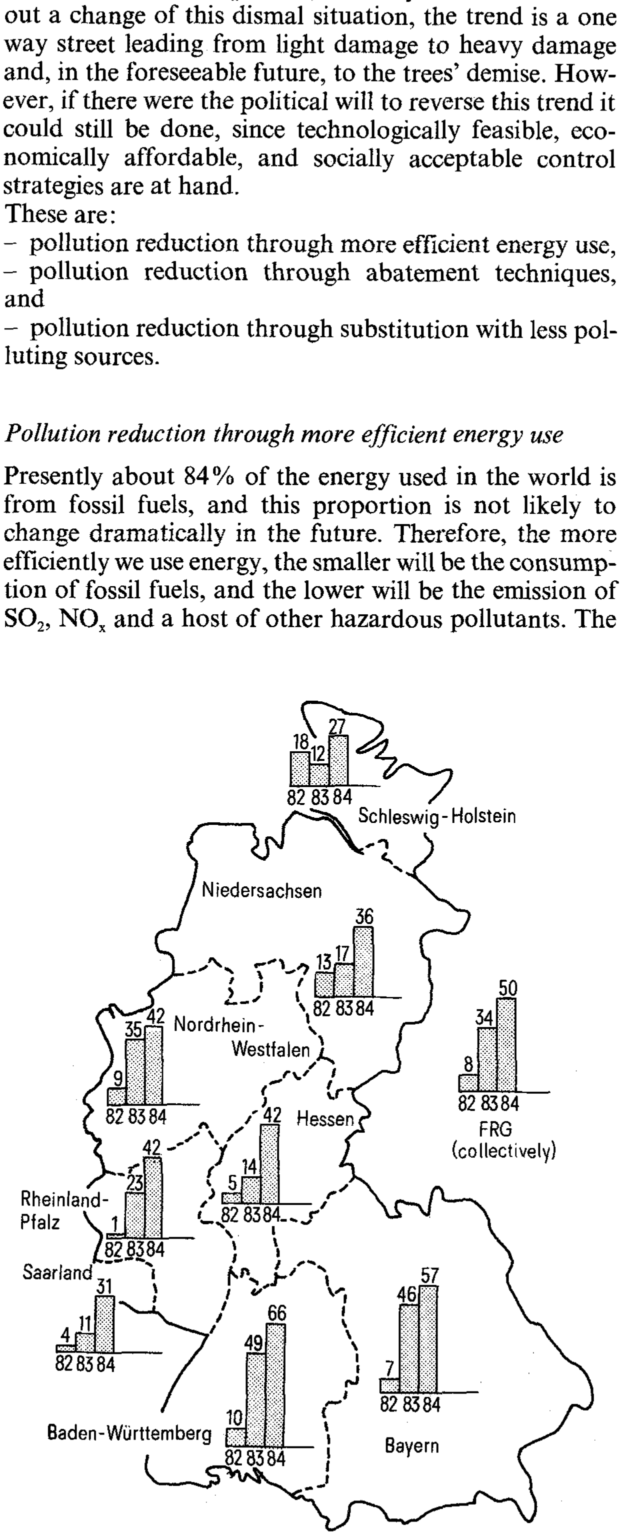

Figure 2. Trend and areal distribution of damaged forest in the FRG. Data extracted from BML[12].

Residential and commercial sectors

Energy consumption in the German building sector is accounted for in large part by space heating (82%), followed by process and hot water heat (12%), and electricity for light and appliances (6%). Of the total end-use energy the largest share falls on space heating (35%) indicating its dominating role in energy use but also its large potential for efficiency improvements. The contribution of this sector to the emission of 3 million t of SO_2 and 3.1 million t of NO_x in 1982 was 18% and 5%, respectively[13].
The present state of the art for new residential buildings is characterized by 'superinsulated' or 'micro-energy' houses[5]. This construction practice can lower gross shell heat losses so much that internal heat gains from occupants, lights, cooking and appliance use, as well as passive solar gains through windows, suffice to give normal comfort without supplementary heat even at outdoor temperatures as low as $-5\,°C$[56]. More than 1000 superinsulated houses have been built in Canada and the USA. The additional costs (found in sample surveys) amount to about C$3100. Amortization occurs within 5–10 years. Existing buildings can be retrofitted using outside and/or inside wall insulation, vapor barriers, weatherstripping, triple-glazed windows, insulating windows, insulating window shutters and shades, roof and basement insulation, mechanical ventilation with heat exchangers, and passive solar features. Costs for retrofitting range from $100 to $200/m² floorspace in Germany[39].
In the 1970s, heating systems in Germany had an average end-use conversion efficiency of about 50%[51]. There is much room for efficiency improvements in old and new buildings through exhaust-stack lids, outdoor and indoor electric sensors and thermostats, thermostatic valves, electronic fuel-air mixing regulators, smaller peak furnace capacities for better load matching, insulation of distribution pipes and ducts, and regular maintenance. Further improvements are possible with new pulse-combustion furnaces achieving efficiencies in excess of 90%. District heating systems and decentralized supply systems such as total-energy modules for cogenerating heat

and electricity can offer improvements both in end-use efficiency and in the conversion of primary fuel[64].

More specifically, table 5 shows the savings in primary energy with various heating technologies as compared to a conventional oil central heating system[20]. The reduced primary energy demand is translated into reduced SO_2 emission. Most effective are the gas heat pump, passive-solar construction with insulation, and insulation plus double glazing. Note, on the other hand, the significant increase in SO_2 emission if electric heat pumps and direct electric night-time heat storage are used.

Electricity-specific functions both in the residential and the commercial sectors offer wide room for improvements. These include heat insulation (in refrigerators, freezers, dryers, ovens, and washing machines), better heat pumps (in refrigerators and freezers), more efficient motors and drives, and better electronic devices and light bulbs[48]. High-pressure lamps, task lighting, and daylighting promise further savings. Sodium-vapor, quartz-halogen lamps are now available that use 75% less current than conventional light bulbs while lastings 4–5 times longer.

All of these measures used individually or in combination can contribute substantially to the reduction of pollution emission.

Transport sector

About 19% of the German energy is used for transport, and more than half of that for automobiles. Of the 3.1 million t of NO_x emitted per year about half of it is produced by traffic[13]. The many available technical options for improving the performance and reducing the cost for the user have been reviewed[26,61,63]. The average German car efficiency was 10.6 l/100 km (22.5 mpg) in 1973. Table 6 shows a partial listing of the efficiency improvement potential of cars. It must be noted that the individual fuel savings are not simply additive but that they must be weighted according to the savings already achieved. In a one-year test in the early 1980s, the US EPA achieved a performance of 3.0/2.4 l/100 km (80/100 mpg) on the city/highway circuit in the Washington DC area using a VW Golf (Rabbit) prototype[44]. The cost for improvement to only 4 l/100 km (60 mpg) would already save the average user, at current gasoline prices, some $545/yr. The extra capital costs for the car improvement could be payed back in less than three years. Improvements beyond 4 l/100 km are economically attractive. Substantial efficiency improvements are also possible for trucks and buses, trains and ships, as well as aircraft.

While the fuel efficiency has been improved in most cars over the past ten years, this welcome effect has been more or less nullified by the trend to bigger and hence heavier cars. The often-made assumption that bigger and faster cars emit less pollution than smaller ones, because they arrive sooner, is false. In fact the greater weight and the higher speed of bigger cars is more important, and this leads to more pollution per kilometer travel. Compared to 100 km/h (62 mph), cars at 150 km/h (93 mph) use 1.7 times more fuel and emit 3.8, 2.3, and 1.5 times more CO, NO_x and hydrocarbons (HC), respectively[34]. They have also calculated that the introduction now of a speed limit of 80 km/h (50 mph) on interstate roads and 100 km/h (62 mph) on freeways could reduce the total annual emission from traffic by 270,000 t (16%), 600,000 t (11%) and 30,000 t (5%) for NO_x, CO, and HC, respectively. Beside the important reduction in the NO_x and HC emissions which are the main ingredients in the photochemical oxidant formation, now considered a major contributing factor to forest dieback, there are many other beneficial effects to be expected from a speed limit; the main one would be a drastic reduction in the frequency of death and in jury on the roads in the FRG, which has the distinction of having one of the highest rates in the world.

Table 5. Effect of efficiency technologies in primary energy use and SO_2 emission in the residential sector[a]

Measure	Savings in primary energy[1] (%)	Estimated reduction in SO_2[1] (%)
Oil heating system (base value)[2]	0	0
Improvement in engineering design[3]	5–20	5–20
Insulation, double glazing	20–70	20–70
Heat recovery, insulation, passive-solar construction	30–90	30–90
Solar collectors plus oil heating system	25–50	25–50
Heat pump (Diesel)[4]	ca. 65	ca. 65
Heat pump (gas)[4]	ca. 65	ca. 100
Heat pump (electric) plus oil heating[5]	5–10	Increase by 150
Heat pump (electric monovalent)[5]	Increase by 30	Increase by 300
Direct electric nighttime heat storage[5]	Increase by 300	Increase by > 300

[1] Values are not accumulative. [2] All percent values are related to a conventional oil heating system; emission factor 200 kg SO_2/TJ. [3] E.g. electronic sensors and thermostats, thermostatic valves, electronic fuel-air mixing regulators, etc. [4] Monovalent system. [5] Emission factor 6×10^{-3} kg SO_2/kWh for electric current. [a] Adapted, with consent of the publishers, from Fritsche[20].

Table 6. Efficiency improvements in automobiles[a]

Measure	Savings (%)	Fuel savings at specific measures (l/100 km)
Average car (1973)	0	10
Replacement of steel and iron by		
– plastics	6	9.4
– aluminium	13	8.7
Reduction of aerodynamic drag	4	8.4
Radial tires	2	8.2
Diesel instead of gasoline	15	7.0
Improved motor, lubricants and drive-train components	25	5.2
Idle-off systems	8	4.8
Continually variable transmission	10	4.3
Stratified-charge low-RPM engines	25	3.6
Regenerative braking and energy storage	8	3.3
Reduction of weight	25	2.5

[a] Adapted, with consent of the publishers, from: Krause, Bossel, Müller-Reissmann[39].

Industrial sector

Industry's share of the FRG end-use energy amounts to about 38% with more than half of that going to steel, chemicals and cement production. The technology changes necessary to keep the German steel industry competitive would already result in a 40% reduction of primary energy use, if waste heat and by-product fuel gases were recovered. Process technologies change rapidly in the chemical industry and the related efficiency improvements could save half its total energy. Heat recovery, better insulation, and more efficient grinding methods etc. could save the cement industry one third its total energy. Moreover, energy can be saved from recycling of materials, eliminating unnecessary materials in products, and increasing product lifetimes[16,18].

The overall efficiency of conventional power plants could be increased from about 36% to 85% simply by cogeneration, i.e. by combined heat and power generation. By building decentralized neighborhood cogeneration systems, the losses incurred in transporting energy and the investment needed for grid systems could be significantly reduced. With fluidized bed combustion, not only is efficiency increased by 10%, but also the emission of SO_2 and NO_x is reduced drastically[30,57].

The comparison of energy efficiency with exergy efficiency in table 7 gives a good indication of the wastefulness of current energy production and use. The degree of energy efficiency is a measure of how much of the original energy content in coal, oil or gas is found in the end-product such as electricity. The degree of exergy efficiency is a measure of the energy quality of the end-product such as electricity in comparison to the primary product such as coal[67]. Clearly, large power plants, which emit almost ⅔ of their high quality energy input as waste heat, fail even more dismally when we realize that they produce only 8% high quality end-product-energy. This is only ⅕ of that produced by cogeneration of power and heat. Gasification and liquefaction methods, beside producing substantial amounts of pollution, result in equally low end-product-energy-quality as large power plants. Also, a power plant producing only heat results in less high quality energy than one that combines power and heat production.

All of this clearly shows that cogeneration is the thermodynamically and economically best method of producing energy. Cogeneration works best in small decentralized units, thereby cutting down transmission losses and transmission costs. Also, the more efficient use of energy input will automatically reduce drastically the ca. 80% of SO_2 and the ca. 45% of NO_x emissions from both power plants and industry[13]. The 1982 FRG power plant capacity of 90593 MW represents a 30% overcapacity for a generally accepted reserve of 20%[21]. This means that the outmoded large power plants of today, which are highly inefficient and are major polluters, can be phased out and that new ones are not required. They should be replaced expeditiously by cogeneration plants. This control strategy must be supplemented, at the same time, by abatement techniques for stationary and mobile sources.

Table 7. Comparison of various efficiencies in energy production[a]

Technology	Energy efficiency (%)	Exergy efficiency end product (%)	Exergy efficiency its use for heating (%)
Large power plants without use of waste heat	38	38	8
Cogeneration	70–80	43	43
Heat production plant	85	24	24
Coal gasification	45–55	45–55	7–9
Coal liquefaction	47–52	47–52	7–8

[a] Adapted, with consent of the publishers, from Teufel[67].

Pollution reduction through abatement techniques

The available abatement techniques for stationary sources (power plants, industrial plants, boilers/burners) can be grouped into three main categories[1,54,65,66]:
- those that reduce emissions *prior* to combustion (coal cleaning, coal gasification and liquefaction, desulfurization of liquid fuel)[31,47];
- those that reduce emissions *during* combustion (burner technology, fluidized bed combustion)[7], and
- those that reduce emissions *after* combustion (flue gas desulfurization, NO_x technology)[3,72].

Coal cleaning

Bituminous coal contains both pyritic and organic sulfur in roughly equal proportions. Coal washing is standard practice for the removal of ash. Washing and other separation techniques used to remove pyrites can reduce the sulfur content of coal by 40–60% by weight at a cost of \$2.50–\$3.25/t (at 1975 US prices). However, these processes cannot remove the organic sulfur in the coal.

Coal gasification and liquefaction

Currently available techniques can remove up to 90% of the sulfur from the gaseous and liquid fuels. The costs of sulfur removal are likely to be low compared to the costs of gasification or liquefaction.

Desulfurization of liquid fuels

There are a number of processes available. Desulfurization of gas oil achieves a sulfur removal of 90% requiring an additional 3.5% of energy for the removal process. Direct residual fuel oil desulfurization can reduce the sulfur level of the residue by ca. 80% requiring 6–8% additional energy of the feedstock. The degree of desulfurization that can be achieved by the indirect method of residual fuel oil desulfurization is only about 30–45%; and the additional energy consumption is about 5%. Desulfurization plants require for planning and construction a lead time of 3–5 years.

Burner technology

Through the use of multistage burners, 80% of the SO_2 and 50% of the NO_x can be removed as compared to emissions from conventional burners. The additional cost of combustion modifications is generally less than 1% of the capital cost of the power plant.

Fluidized bed combustion

The boiler consists of a reaction chamber in which finely ground coal is burned in suspension over a bed of moving air in the presence of fragmented limestone capable of removing SO_2. The movement of the coal particles gives a larger heat transfer thereby making a boiler of half the usual size possible and improving the energy efficiency by 10%. Fluidized bed combustion is most suitably used in connection with smaller-scale cogeneration plants, thereby reducing the waste heat release by 80%, the SO_2 emission by close to 95% and, as a result of the lower combustion temperatures (800–900°C as compared to the usual 1600°C), the NO_x emission by about 75%. Many experts consider this a most promising process. Additional investment costs are less than \$10/kWe (in 1982 US\$)[66].

Flue gas desulfurization and NO_x control

There are two main processes for flue gas desulfurization, the dry and the wet scrubbing of stack gases. In the dry process gases pass through a bed of absorbant, such as activated coal, which reacts with the SO_2 in the flue gas. When the absorbant is fully loaded with SO_2, clean gas is passed through the bed, stripping out the SO_2, which is subsequently converted to sulfur or sulfuric acid. The dry method can only remove some 50% of the SO_2 in the stack gas. In the wet process the gas is washed with an alkaline solution removing up to 98% of the SO_2 from the stack gas[1]. The SO_2 is converted to a waste product (sludge) or to a saleable by-product (gypsum). The sulfur that emerges with the solid residues as calcium sulfate can be sold as a fertilizer if it is not loaded with heavy metals[55].

Catalytic methods achieving NO_x removal rates of up to 80% are practised widely in Japan. The costs of the systems amount to about 5% of the total cost of generating electricity. Significant advantages of the method over the coal conversion route are that the total capital and operating costs are almost an order of magnitude lower, that thermal efficiencies are higher, and that utility requirements are lower[72].

Table 8. Efficiency and costs of various emission reduction technologies for large power plants and small boilers in the FRG[g]

Technology	Pollutant (% reduction) SO_2	NO_x	dust	Costs marks per kW	pfennigs per kWh
Fuel desulfurization	30	–	–	–	10–20[a]
Fuel gas desulfurization					
wet	> 95	–	> 30	80–150	0.5–2[b]
dry	< 50	–	–	15– 40	0.1–1[b]
Low NO_x burner	–	50	–	10– 20	–[c]
Low NO_x boiler	–	50	–	20– 25	–[c]
Selective catalytic reduction	–	> 80	–	50– 90	0.5–1.5
Walther process	95	80	> 20[e]	200–250	2.5–3[b]
Fluidized bed combustion	95	< 200[d]	< 20[e]	+15%[f]	+15%[f]

[a] In German marks/t of coal equivalent. [b] Dependent on plant size and life-time. [c] Operating costs negligible. [d] In mg/m³ corresponds to ca. 75% reduction. [e] In mg/m³. [f] Average increase compared to conventional flue gas desulfurization plant. [g] Adapted, with consent of the publishers, from Fritsche et al.[21].

These control measures reduce not only the emission of SO_2, NO_x and dust, but also that of HCl, HF and heavy metals etc. Table 8 summarizes the efficiencies and costs of the various technologies[21]. The costs of emission control range between 5 and 25% of the capital costs. The additional costs for SO_2- and NO_x-reduction correspond to a 15–20% increase in fuel costs.

Catalysts in cars

Traffic pollution can be significantly reduced by introducing more efficient cars and speed limits as shown above, as well as through leadfree gasoline, lean fuel mixtures, car pooling, more extensive use of public transportation, partial redirection of transport of goods from road to rail, and traffic-free days, etc. However, in the long run one of the most effective measures for reducing pollution from gasoline motors is the three-way catalyst (which reduces the three pollutants NO_x, CO and HC) used with a lambda-sonde (an electric device that procures an air to fuel ratio of 14.6 to 1 required for complete combustion)[10,11,38]. This type of catalyst can reduce NO_x, CO and HC by about 70, 85 and 80%, thereby achieving the US standards of 0.62, 2.1 and 0.25 g/km, respectively. In the following we shall concentrate on the NO_x-emission, because it is instrumental in the formation of photochemical oxidants which are now believed to be a major contributing factor to the continuing forest dieback.

Currently, of the 3.1 million t of NO_x emitted per year in the FRG, transport contributes some 1.7 million t[34]. Of this amount 1.04 million t are produced by gasoline motors (840,000 t on freeways and interstate highways, 200,000 t within city limits), 470,000 t by trucks, 70,000 t by civil aviation, ships and locomotive engines, 70,000 t by military use, and 60,000 t go to such miscellaneous sources as motor bikes and tractors etc. Catalysts work only with gasoline engines so that only some 60% of the total NO_x pollution in the transport sector can be eliminated. For an annual replacement of old cars by 8.3% new cars, and assuming a catalyst efficiency of 85% over its lifetime, mandatory catalyst use will reduce NO_x emission by 4.3%/yr. Voluntary introduction of catalyst will achieve even less.

The EG compromise for catalyst use reached in spring of 1985 is as follows: US standards are to become mandatory for new cars larger than 2000 cc in 1989, and for cars between 1400 and 2000 cc in 1993, which would mean a 90% reduction over cars without the catalyst. For cars smaller than 1400 cc the prescribed pollution reduction is only 50% beginning in 1991. According to IFEU calculations this latest effort to reach US standards 20 years after introduction in the US would cut down the FRG NO_x emissions in 2000 to the 1977 level. It is more than doubtful whether this meager control effort could make much of a contribution to halt the galloping forest dieback. Table 9 summarizes the measures and costs of some of the major control strategies discussed above. Considering the EG constraints it is apparent that the best control strategy left involves the more efficient use of energy, the various methods of pollution control at the source, and the instant introduction of speed limits.

Pollution reduction through substitution with less polluting sources

The third control strategy presented here is more of a long-term nature. The more widespread use of renewable energy resources and nuclear energy has been suggested as a substitution strategy for reducing SO_2, NO_x, and a host of other hazardous substances. Except for biomass burning which would produce small amounts of SO_2 and NO_x as compared to fossil fuel burning, all other solar-based renewable resources operate pollution-free.
The potential of nuclear energy for substituting fossil fuels with the purpose of reducing the acid rain threat is not so clear, and the question thus warrants a closer look. In the FRG nuclear energy produces about 30% of the electricity (which itself accounts for about 15% of the end-use energy) so that it supplies approximately 4.5% of the end-use energy. In 1980, savings in the use of heating oil alone amounted to about 10% of end-use energy. German power stations use less than 5% of the total oil to produce electricity. More than 53% of the oil is used to produce heat. Thus, to make a noticeable contribution, atomic power would have to penetrate the heat market. A power plant of the Biblis type (1300 MW) would produce about 6.8 billion kWh/yr or 0.84 MTCE electricity equivalent, taking a load factor of 60%. The present German oil consumption is about 190 MTCE. Thus 10 large atomic power plants could just replace barely 5% of the oil, half that achieved through savings in the heating oil sector alone. The situation is not much different in other industrial nations[9].
With the siting and acceptance problems inherent in atomic power plant construction, it would take at least 10–30 years to put on line the 30–40 large atomic power plants required as a minimum to replace the existing fossil fuel plants in Germany. This, very definitely, would come too late to halt the acid rain catastrophe.
The 30–40 atomic power plants would require an investment sum of at least 190 billion marks at current prices – ignoring all corollary costs. According to the German utility industries desulfurization of the stack gases by 50% of the current values in all existing fossil fuel power plants would require an investment of some 6 billion marks – or just the construction costs of one single 1300 MW atomic power plant[37].
Finally, the suspicion is growing that atomic power is also a contributing factor to forest dieback[52,53]. Recent forest damage inventories have revealed for a number of atomic power plants (Obrigheim, Würgassen and Esenshamm in Germany as well as Bugey in France) that forest damage is significantly enhanced downwind of the main wind direction. In the vicinity of the Karlsruhe reprocessing plant it was found that Krypton (^{85}Kr) in air, and tritium (^{3}H) in water and in pine needles had increased by a factor of 5000, 40–160, and 9, respectively. ^{14}C, ^{85}Kr and ^{3}H are known to reduce the enzymatic power of plants to repair damage so that the more conventional pollutants (SO_2, NO_x, O_3, heavy metals etc.) can have a greater adverse impact.
To these adverse effects must be added the many other risks from atomic power including the release of radionuclides to the environment involving the entire fuel cycle, the likelihood of accidents, the disposal of wastes and the proliferation of fissionable material which could be used for the purpose of building atomic bombs. For all these and the above reasons atomic power is quite unsuitable as a strategy to replace fossil fuels and hence to reduce the acid rain/forest dieback threat.

Table 9. Measures and costs for air pollution reduction in the FRG[a]

Measure	Costs in billions of German marks per year	Emission reduction of total
Desulfurization of power plants and other large combustion facilities	Until ca. 1990: 1.2, thereafter ca. 0.3	After 1990: 60% SO_2
DENOX technologies for power plants and other large combustion facilities	Until ca. 1990: 0.4	After 1990: 20% NO_x
Speed limits (100/80 km/h)	None	Instantly: 12% NO_x
12 auto-free sundays per year	None	Instantly: 1% NO_x
Catalysts for new cars	3*	After 1995: 25% NO_x
Total	4.6	ca 60% of the SO_2 and NO_x emissions

* Pending regulations. [a] Adapted, with permission, from IFEU[33].

Conclusions

It is safe to conclude that hypotheses which relate forest dieback to any one single cause fail to explain this complex, multiple stress phenomenon. There is a host of contributing factors including, beside SO_2, NO_x and acid rain, photochemical oxidants, heavy metals, pathogens, forest management, climatic factors, radioactive radiation, and perhaps also electromagnetic waves. There is a growing concensus among scientists that pollutants weaken the trees' resistance so that they fall prey more readily to other adverse influences. The trend of the damage is such that it will lead, in the foreseeable future, to the trees' demise. Besides the trees, buildings, animals and humans are affected, too, and man's very life is severely threatened by the ongoing poisoning of the air, the water and the soil.
Responsible for the forest dieback is, above all, the squandering of fossil fuels and the tall stack policy which, instead of sequestering the pollutants from the gas stream at the source, allows them to spread over wide areas, thereby turning an initially local problem into a large-scale and international one. The current type of forest dieback, which has not been observed before, proceeds at an unprecedented speed. To reverse this adverse trend, also unprecedented efforts are required.
Therefore, at this late stage, it is no longer justified to wait for an all-inclusive diagnosis of the complex disease forest dieback before taking curative action. Rather, a better strategy is to continue with the detailed documentation of forest damage and use this as a means of pressure for introducing control measures that will be effective immediately. To reverse the adverse trend there are three basic measures available which are technically feasible, economically affordable, and socially acceptable.

These are
- pollution reduction through more efficient energy use,
- pollution reduction through abatement techniques, and
- pollution reduction through substitution with less polluting sources.

Pollution control at the source brings the necessary relief in the short run, stabilizes the emissions in the medium run, and reduces the impacts in the long run. However, in the long run a sustained remedy can only come from the more efficient use of our non-renewable fossil fuel resources, thereby reducing the need of having to burn them in the first place and cutting pollution emission at the same time, and from the increased use of less polluting renewable energy sources.

The present state-of-the-art offers a wide array of control measures. The highest priority should be given to cogeneration with fluidized bed combustion for stationary sources, and speed limits in combination with catalysts for mobile sources. In the FRG, this requires a complete revision of the out-dated energy act and a strenghtening of the ordinance for large combustion facilities supplemented by stricter ambient air quality standards on the home front, and a concerted supranational action on the international front. All of this can be done, if there is the political will to do it. An enlightened public can influence the decision-making process – especially before elections.

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Heavy metal levels and cycling in forest ecosystems

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Key words. Heavy metal; spruce ecosystem; trace element input; trace element turnover; soil macrofauna; Black Forest.

1) Physiological effects of heavy metals in plants

Heavy metals can be essential, beneficial or toxic for forest ecosystems. A number of heavy metals are essential nutrients for plants, animals, and men. An insufficient supply may therefore lead to deficiency symptoms in forest trees. Zinc deficiency occurs in large areas of Australia and New Zealand where pines were afforested on poor soils[26,31], and also on latosols in southern Brazil[22]. Copper deficiency is known for *Larix* and *Pseudotsuga* on heath podsols in Western Europe[28]. Manganese deficiency in *Pinus* and *Picea* is found on calcareous mineral soils and calcareous lower moorland, e.g. in southern Bavaria[15]. Iron deficiency may also occur on such sites[32]. The deficiency may be due to low reserves of these elements in the bedrock or soil or may be caused by extensive fixation in the rooting zone.

There are sites with an extremely high content of heavy metals in minerals and soils. This prevents tree growth, and only adapted (tolerant) plants are able to develop; well known examples are sites on serpentine with very high concentrations of nickel, chromium, and cobalt, or plant communities with *Viola calaminaria*[2]. In these cases high concentrations of heavy metals can be toxic. Tree species differ in their tolerance to high heavy metal concentrations. On moist and acid soils with a high mobility of manganese, spruce and silver fir accumulate an extremely high content of this element in their needles whilst, however, showing good growth[18]. The same applies to Scots pine[29].

There is also a species-related difference in tolerance to toxic elements such as cadmium, lead, chromium, and nickel. This is shown in table 1. *Populus* and *Betula* (as well as *Salix*, which is not listed) accumulate zinc and cadmium in their leaves when cultivated in sewage sludge strongly contaminated with heavy metals. *Quercus* has in comparison a higher copper uptake. No toxic effects were noticed during this experiment.

2) Damaging effects in the vicinity of sources of emission

Extensive contamination of the biosphere with heavy metals occurs mainly in the vicinity of sources such as