10. Sulphur dioxide: from protection of human lungs to remote lake restoration

Arne Semb

In December 1952 a dense smog — a mixture of fog and coal smoke — descended on London. Records from London's hospitals showed that more than 2 000 people died from the exposure to air pollutants during one week, and there was strong pressure that this should never happen again. Yet the 1952 London smog incident was not unique (Brimblecombe, 1987; Ashby, 1981). Worse smog incidents had occurred previously in London, and the air quality there, as well as in other cities in the United Kingdom was actually improving, not deteriorating. What was new was the political and social set-up after the war, which meant that the public was no longer willing to accept the situation. The incident was also well documented, both with respect to health effects and air quality. The measurements made by the scientists at St Bartholomew's Hospital showed that the concentrations of smoke particles and sulphur dioxide reached several milligrams per cubic metre. A parliamentary commission prepared a special report named after its Chairman, Sir Hugh Beaver.

The remedies that the Beaver Report could propose were modest. London was entirely dependent on coal for heating and energy purposes, and coal contains sulphur which can only partly be removed prior to use. So, the subsequent Clean Air Act instead considered the smoke component of the air pollution, allowing the local councils to establish 'smoke-free areas', in which the infamous coal fireplaces were to be replaced with more efficient combustion units, electricity and 'smokeless fuel'. Emission sources other than domestic fireplaces were to be 'as far as possible' smokeless. A revision of the Alkali Act in 1958 provided the Alkali Inspectorate with more authority in relation to industrial pollution sources, but did not specify emission limits or standards. 'Best practicable means' was the governing principle. In practice this meant that the main method of reducing sulphur dioxide (SO_2) concentrations at ground levels was the use of tall chimneys, in proportion to the emitted amounts. These were obvious steps in the right direction, but slow, and a second smog incident that occurred in 1962 with about 800 additional deaths further demonstrated the need for action.

Oil from the Middle East became available in large quantities after 1950, and was to become the main source of energy in western Europe during the following two decades (Mylona, 1996). As refining was relatively primitive, a substantial fraction of the production was heavy or residual fuel oil, with a sulphur content of 2.5–3 %. Gas oils with less than 1 % sulphur were also marketed as fuel oil for use in small boilers and in the domestic market. Heavy fuel oil was used in the new electrical power generating plants in many countries in Europe, particularly in countries with no indigenous coal deposits, but also in the United Kingdom. It was also used in boilers for central heating in large building complexes, hospitals and other service buildings, and in industry. However, growing environmental awareness in the 1960s led to concern in cities across Europe about air quality, and restrictions with respect to the use of different qualities of fuel oil and their sulphur contents began to appear. In fact, some cities had experienced black smoke and SO_2 concentration levels comparable to those in London, but caused by the use of sulphur-containing fuel oil with improper combustion.

The Organisation for Economic Co-operation and Development (OECD) had set up an Environmental Section in Europe in the late 1960s and after 1971 representatives of the member countries would meet in an Air Management Sector Group to discuss common problems and experience. In turn, this group took up the problems of urban air pollution, acid rain and photochemical oxidant formation, and made useful contributions to their solution.

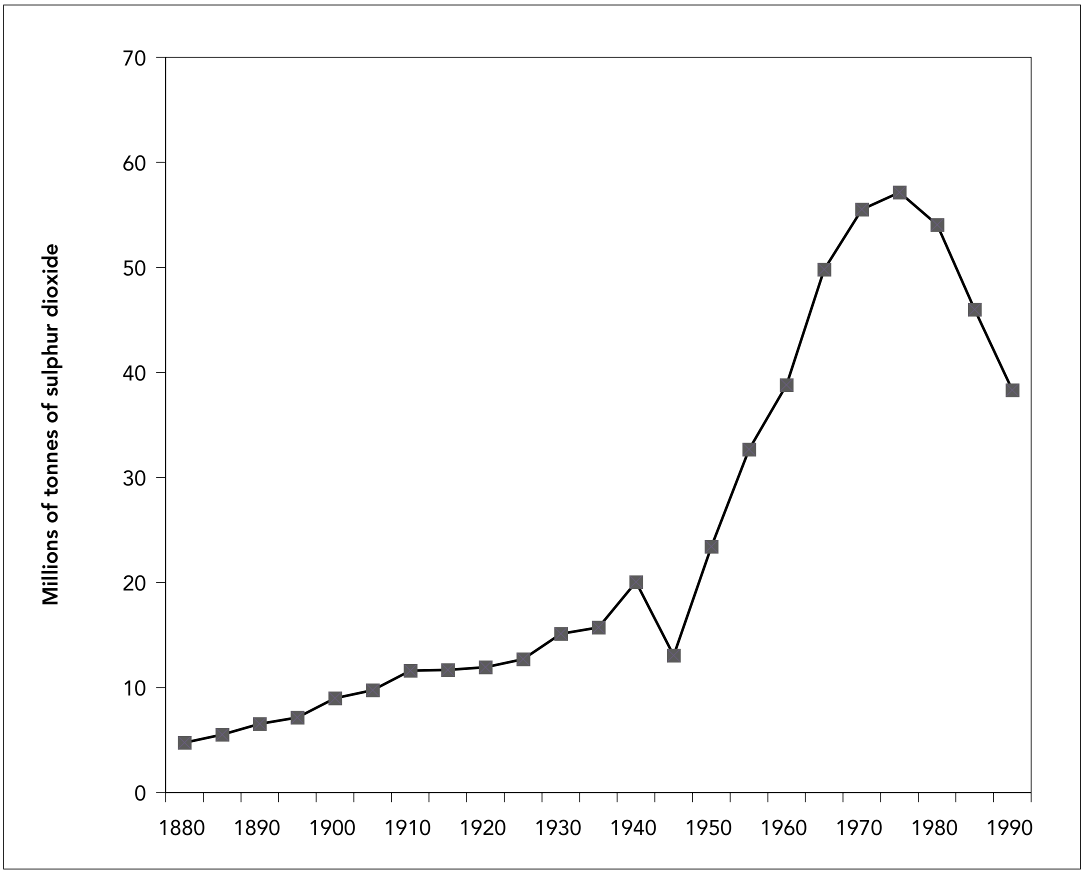
The question of air quality standards, or guidelines, was particularly useful in connection with the planning of new industries and licensing of combustion sources. There was a good deal of reluctance to accept fixed limits, which were mainly introduced to Europe under the influence of the example of the US Clean Air Act (United States of America, 1970). However, Professor Lawther of St Bartholomew's had already determined (WHO, 1972), on the basis of the deaths during the London smog, that health damage occurred whenever concentrations of SO_2 and black smoke, respectively, rose above 500 and 250 micrograms per cubic metre (Mylona, 1996). Since concentrations of pollutants are extremely dependent on weather conditions, air quality standards have to be fixed at considerably lower average levels, in order to safeguard the public against harmful exposures. Countries have had different attitudes to the establishment of air quality standards, and particularly to their enforcement in relation to emission controls. Nevertheless, by collecting the available documentation about health effects, the World Health Organization (WHO) has since 1979 recommended air quality guidelines that set a standard for the pollution abatement work in Europe (WHO, 1979 and 1987).

10.1. Dead fish, dying forests

Increasing energy consumption in Europe during the 1960s resulted in a large increase in emissions of SO_2. Much of the increased energy consumption was in the form of electricity, produced in large thermoelectric power plants, and the SO_2 was released from chimneys more than 100 metres tall. As a consequence of this, as well as from the increased chimney heights in industry and in cities, surface air quality was gradually improved in spite of the increased emissions. Optimistic representatives of the electricity generating industry were confident that the emissions could be diluted and dispersed to levels that were not harmful.

This was not so. While British and other European countries were striving to improve the urban air quality, energy consumption and total emissions of sulphur dioxide in Europe increased dramatically, as shown in figure 10.1. In Sweden the soil scientist Hans Egnér had initiated measurements of air and precipitation chemistry across Europe (Egnér *et al.*, 1955), supported by the meteorologist C. G. Rossby. Their primary interest was the supply of plant nutrients by precipitation, and the link with meteorology. However, in 1968 one of their colleagues examined the results and concluded that the precipitation was becoming more acidic as a result of increasing SO_2 emissions, and coupled this to observations of acidification of Swedish rivers. Svante Odén chose to present his results with sweeping statements of their implications, not only in a bulky report but also in a newspaper article (Odén, 1968 and 1967). Sweden chose also to give this as a case study at the 1972 UN environment conference in Stockholm, with evidence of the dispersion, deposition and effects of SO_2 and 'acid rain' (Sweden, 1971). As intended, the creative presentation of this information caught the interest of the international community. Was it really possible that releases of SO_2 in England could change the water quality in Scandinavia, causing fish deaths and reducing forest production? Clearly, more documentation was needed.

Annual emissions of sulphur dioxide in Europe 1880–1990 — Figure 10.1.



Source: Arne Semb (based on Mylona, 1996)

Plans for a more comprehensive study of the transport of air pollutants across national boundaries in Europe had been discussed in the OECD Air Management Sector Group since 1969. In 1972 a cooperative study was launched, with the participation of 11 member countries. Of the European OECD countries only Spain, Portugal and Italy decided not to participate, because they felt that the issue was not relevant to their situations. By arrangement within the Nordic countries, the Norwegian Institute for Air Research (NILU) was given the task of coordinating this long-range transport of air pollutants programme. The report was completed in 1977, establishing exports and imports within the countries of Europe and determining the relationship between emissions and deposition of sulphur compounds (OECD, 1977). It was now quite clear that acidification in Scandinavia could be quantitatively related to emissions in several European countries, and that these countries were responsible for the damage which occurred from acid rain. A very ambitious Norwegian research programme had been started in 1972 on acid precipitation and its effects on forests and fish, and by 1976 an interim report was prepared which showed widespread acidification of rivers and lakes, and strong documentation of the declining stocks of both trout and salmon in such areas (Braekke, 1976). The report was not released, however, as the project was presented to an international audience in June 1976 (Knabe, 1976; *Ambio*, 1976). The suspected effects on forests were, however, much more difficult to demonstrate. The SNSF project was finalized in 1980 (Overrein *et al.*, 1980; Drabløs, 1980).

Although strong scientific evidence was now available, resistance to change was strong. An editorial in the UK-based scientific journal *Nature* (Nature, 1977) claimed that acid rain was a million-dollar problem with a billion-dollar solution, referring to the value of the fish and the costs of installing and operating flue gas cleaning on electric power plants. The reply from Erik Lykke (Lykke, 1977) at the Norwegian Ministry of the Environment stated that this was obvious, but that the cost-benefit analysis was incomplete. Emitter countries such as the United Kingdom should also consider the damages caused by releases of SO_2 in their own countries, to health, materials, agriculture and to natural ecosystems. If all these damages were considered, the economic benefits of reducing the emissions would also be obvious. It was not a case of Europe *vs.* Scandinavia, it was Europe versus itself.

A cost-benefit study carried out, again by the OECD (OECD, 1981), confirmed that the value of the lost fish populations was small in economic terms. The perceived costs in terms of timber production were also not particularly significant, but the damage caused to buildings and construction materials was shown to entail comparable costs to that of reducing emissions by flue gas cleaning and fuel desulphurisation.

In the event, the oil companies would also benefit from fuel desulphurisation, because of the higher profits from light and low-sulphur distillation products, compared to heavy fuel oil. The oil companies were well aware of this, and had already started restructuring the refinery industry to produce less heavy fuel oil, and more light and medium distillates, removing as much as 70 % of the crude oil's sulphur content in the process. This move was also a result of the high oil prices following the 1973 oil crisis, which made western European countries aware of their reliance on the oil supply for electricity production. This resulted in the conversion of oil-fired power plants to coal and building of new coal-burning power plants, while France switched to the use of nuclear energy for electricity production.

The situation in central and eastern Europe was different. In the German Democratic Republic (GDR), Czechoslovakia and Poland, energy and industrial production had been increased mainly by the use of large amounts of low quality coals with high sulphur contents, as the old, high-quality coal seams were depleted. The results were dramatic as the SO_2 emissions in these countries increased by a factor of 10 from 1960 to 1985, when these three countries alone emitted more SO_2 than all other countries in northwest Europe together.

To combat acid rain and SO_2 emissions without the participation of the Eastern bloc countries was clearly not possible. East-West political relationships were tense during the Cold War period, and the discussions in the Conference of Security and Cooperation in Europe in Helsinki in 1975 were difficult. In fact, the two factions could reach agreement on one issue only: cooperation on the issue of airborne pollutants. Countries from both sides agreed to establish cooperation under the Economic Commission for Europe (ECE), in Geneva, with participation from the World Meteorological Organization and the United Nations Environment Programme. A cooperative programme for monitoring and evaluation of long-range transmission of airborne pollutants in Europe (EMEP), was initiated in 1976, and was followed by the Convention on Long-range Transboundary Air Pollution (CLRTAP), in 1979. This convention expressed the signatories' intentions to investigate the problem, to exchange information about emissions as well as effects, and to reduce, as much as possible, emissions causing harmful effects. The convention also set up a number of task forces and cooperative programmes in addition to EMEP, which were to prepare assessments information for future protocol negotiations.

By this time, forest decline had become a hot issue in Europe. Following releases by German forest scientists at the University of Göttingen (Ulrich *et al.*, 1980), a series of articles in the German popular journal *Der Spiegel* exposed the issue of 'neuartiger Waldschäden', or new forest damage. It appeared that forest damage was widespread across Germany, but mainly along the border with the GDR and Czechoslovakia. It was also most pronounced in freely exposed trees, in hilly areas and on ridges. The symptoms were quite general, and might be interpreted as general stress, although needle yellowing implied magnesium deficiency at some sites. Different schools of thought offered at least three different explanations, but none satisfied a stringent cause-effect relationship. Both soil acidification and direct action of air pollutants were held to be responsible, continuing the division of opinion dating back to when concerns first emerged in Germany in the 19th century. Meanwhile, reports of even more serious forest diebacks came from Bohemia and Poland. In the border areas between the GDR and Czechoslovakia, several square kilometres of dead spruce forest were present in the areas now identified as those with the highest concentrations and deposition of airborne sulphur compounds and acidity (Moldan *et al.*, 1992).

By this stage, public opinion and the press had been alerted. Acid rain and fish-kills in remote lakes and rivers were identified in North America as well as in Europe. When forests and terrestrial ecosystems were so apparently endangered, the situation seemed obvious to the public, even if the scientists did not agree on the mechanisms.

In March 1983 the official Council of Environmental Advisers in Germany issued a report to the German Bundestag relating to forest damage (Council of Environmental Advisers, 1983). In their opinion, flue gas desulphurisation should already have been installed at coal-fired power plants where emissions exceeded 400 milligrams per cubic metre of SO_2. But the council was not convinced by the scientific explanation of the new forest damage, and cautioned that SO_2 emission reductions might not improve this particular situation. Action justified on this basis alone might jeopardise the credibility of the environmental policy if subsequently found to be incorrect. In its own words:

'As long as the preventive measures aim at reducing the emissions of the pollutants in question within the scope of a long-term strategy and in appropriate relation, there is hardly any danger of their being classified as unreasonable. This is also valid if the immission situation in clean air areas can only be improved slowly as a result and if positive influences on the vegetation can initially only be surmised. A balanced reduction of the emissions means that one must proceed from the objective criteria which speak for greater or lesser hazard potential of the individual pollutants, and that one must reduce the total spectrum proportional to the apprehension, not in an unsystematic manner or only under the influence of certain popular fears.'

Since much of the damaged forest was located near the borders with Germany's neighbouring countries, international cooperation in research and policy development was also necessary.

10.2. The 1985 CLRTAP Protocol and beyond

The 1985 CLRTAP Protocol, committing countries to 30 % reduction in sulphur emissions, was carried through by the so-called 30 % club, consisting of the Nordic countries, the Netherlands, Switzerland and Austria, and joined by the Federal Republic of Germany. Two countries did not sign the protocol, Poland and the United Kingdom. A somewhat superfluous research programme carried out by the UK Royal Society and the research academies in Norway and Sweden concluded that acid rain did indeed kill fish (Mason, 1992), and the Chairman of the Central Electricity Generating Board in the United Kingdom was impelled to explain to the UK Prime Minister that the accusations made by the Norwegian government regarding the long-range impact of the United Kingdom's coal-burning power stations were scientifically well founded.

Several severe winters with prolonged anticyclonic conditions and easterly flow over northern Europe provided strong reminders of the deterioration of the environment in the Eastern bloc countries during the 1980s. Over large areas of Germany, including western Germany, levels of SO_2 and black smoke were observed that far exceeded the air quality guidelines recommended by WHO (Bruckmann *et al.*, 1986). This experience again demonstrated that tall stacks did not necessarily solve the problem of air pollution with the increased emissions of SO_2 that had occurred. Health warnings were issued to the inhabitants of West Berlin, which were gleefully commented on by the official news services in the GDR. But the source was East Germany, together with the adjoining parts of Poland and Czechoslovakia, in the so-called 'black triangle'. The collapse of the communist regimes which followed was in many ways related to the uneconomic development of energy-consuming heavy industries in these countries, and to the collapse of the Soviet empire which had paid for the products with expensive fuel oil and petroleum products.

Negotiations for a follow-up protocol on sulphur emissions took advantage of this new situation (ECE, 1994). In addition, Germany and some other countries had started on an ambitious programme of emission reductions, installing flue gas desulphurisation and denitrification in both new and old coal-burning electric power plants. In addition to desulphurised oil products, natural gas from Russia and from the North Sea was available to replace coal and sulphur-containing fuel oil. By now, also, the scientific knowledge accumulated in the various bodies and task forces under the CLRTAP could be used to ensure a cost-efficient use of the emission reductions in relation to environmental damage.

One of the main reasons for the wish to reduce the emissions continued to be forest damage, which had been demonstrated in many countries through series of national inventories of tree vitality, involving assessments of crown thinning and leaf and needle yellowing. However, there was still no consensus with respect to the cause, nor was there any indication of quantitative cause-effect relationships. The problem, therefore, had to be attacked from another angle, more precautionary than the prevailing approach, which came to be known as the 'critical load' concept (Nilsson *et al.*, 1988). By definition, the critical load is the highest deposition of a pollutant that does not change the ecosystem in an unacceptable way. For soil acidification this implies a deposition of sulphur (and nitrogen) which is balanced in relation to the release of base cations (such as calcium) from the weathering of soil minerals. In the case of lakes and rivers the acid input must be less than the leaching of base cations in the watersheds. The critical loads may be derived from soil surveys, or surveys of lake chemistry, and have been extensively mapped all over Europe (Hettelingh *et al.*, 1991), providing a rational basis for the negotiations of the 1994 sulphur protocol. Because the sulphur deposition exceedances were mainly located in northern Europe, and because of the state of technical developments, emission reductions were largely called for in this area. It also proved to be too difficult to satisfy the most stringent requirements with respect to critical loads: only a 60 % gap closure was found to be achievable for the grids where the relative exceedances of the critical loads were the highest.

These international negotiations also have implications for urban air quality. It has long been realised that reducing air pollutant concentrations in the cities will have added benefits for human health as well as in terms of reducing material damage. New and stringent limit values for SO_2 and other air pollutants are now included in European Union legislation, taking into account both the benefits of improved air quality and the desirability of reducing emissions (European Commission, 1999). It is interesting, however, to see that the short-term limit for protection of human health, which is set at 350 micrograms per cubic metre for one hour, is still not very much lower than the values proposed on the basis of the experience from the London smog. Limits are also set for 24-hour exposure, at 125 micrograms per cubic metre. It would seem that progress has been slow, as this limit was exceeded for 34 % of Europe's population in 1990 (Stanner *et al.*, 1995).

Damage due to air pollutants has been substantial to materials and historical monuments, particularly to masonry and iron constructions. As concentrations rise above 10–20 micrograms per cubic metre the damage to building materials and historical monuments significantly exceeds the natural degradation occurring in clean environments (Coote *et al.*, 1991). Disfigurement of medieval ornaments and other building details in carved sandstone, sculptures and other works of art, and stained-glass windows, are among the costs not easily quantified. However, a number of retrospective studies have shown that the costs of reducing the emissions have more than been recovered in terms of generally reduced maintenance costs for buildings and steel constructions in the urban environment.

Sulphur dioxide emissions over northern Europe have now been reduced by more than 50 % since the maximum in 1980. Through the use of clean fuels, particularly natural gas, concentration levels in the urban environments have been even more reduced. In the United Kingdom, average urban concentration levels have been reduced by more than 70 %. A new and more stringent protocol to the CLRTAP has been negotiated (ECE, 1994), which will lead to further SO_2 emission reductions. The main emphasis is shifting towards interactions between pollutants such as nitrogen oxides, ammonia and volatile organic hydrocarbons, the combined acidifying effects of sulphur and nitrogen deposition, the formation of photochemical oxidants, and the eutrophication effect of transboundary transport of nitrogen compounds.

The acid lakes and streams show a slow, but steady, recovery (Skjelkvåle *et al.*, 1998). Even forest vitality is improving, according to the latest surveys (ECE and EC, 1997), although the evidence is not unambiguous. It seems that the trout and salmon populations, however insignificant in economic terms, have played an important educational part in making Europe understand the full implications of the emissions of air pollutants.

10.3. Late lessons

So what role has precaution played in this story? Generally action has only been taken on the basis of proof beyond reasonable doubt, and protagonists have felt compelled to justify action on such a basis. Only when the issue was taken to the international level could significant change occur. It was relatively easy for the Scandinavian countries to argue for action, as the initial perception was that they were bearing most of the costs, but few of the benefits, of fossil fuel combustion in other countries. The United Kingdom regarded itself as bearing high costs but gaining little benefit from action to reduce long-distance transportation of sulphur emissions; arguably it was only when it was appreciated that acid rain had costs closer to home that the political climate changed. In the case of eastern Europe, the countries could not afford the short-term costs involved, no matter what the merits of action. Throughout the early history of SO_2 pollution and acid rain, the precautionary approach was altogether absent, mainly because decision-makers had limited understanding of the problems. The tall stack approach was a clear example of the reluctance to accept effects beyond the immediately obvious.

All this was to change perceptibly when the issue came to be the subject of an ECE convention, which was also seen as an important instrument in the improvement of political relations between eastern and western European countries in the 1980s. Another major element was the political pressure of the Green Party in Germany. It is noteworthy that the German Council of Environmental Advisers was concerned that statements about forest damage, couched unjustifiably as a scientific fact, established in terms of proof beyond doubt, could undermine the wider basis for action if these should subsequently be demonstrated as unfounded. If there was general acceptance of the need for action based on a lower standard of proof — a precautionary approach — such potential problems could be side-stepped. In reality, the council's argument was for the record. Politically, the decision had already been taken.

At the international level, the machinery of the CLRTAP had to find a rational approach to negotiations about the limitation and reduction of SO_2 emissions. In principle, the task was to find an approach which minimised the adverse effects, while distributing the costs of emission reductions evenly among the different countries. The many task forces and committees within the convention provided substantial scientific advice and knowledge for this task, and served also to guarantee that the signatories' national interests were taken into account. What the task force on effects came up with was the critical load concept. This can be regarded as related to the precautionary approach because it aims at a situation where no damage or adverse effects are expected to occur. This has the effect of shifting the burden of proof, from demonstrating and calculating in economic terms the damage which could occur in the future from decreased growth of forests, or loss of species, to the relatively simple task of determining which level of deposition can be accepted without perceptible chemical changes in soil composition. With respect to water acidification, the critical loads calculated also represent some simplifications, which are accepted only because of reasonably wide safety margins regarding the survival of sensitive species.

Thus, while not exactly representing an application of the precautionary principle, the application of critical loads represents a rational way of dealing with uncertainties regarding the environmental effects of acid rain.

Table 10.1. **Sulphur dioxide: early warnings and actions**

Source: EEA

1952	A dense smog kills more than 2 000 people in London
1952	The Beaver Report prepared by a parliamentary commission proposes modest remedies
1962	Second smog incident kills 800 people in London
1968	Acidification of precipitation and rivers in Sweden is linked to sulphur dioxide emissions in other countries
Late 1960s	An OECD Air Management Sector Group is set up, contributing to solving air problems
1972	Further evidence of acidification of Swedish lakes presented to the UN environment conference, Stockholm
1972	OECD acid rain study is launched
1972	OECD programme on long-range transport of air pollutants is launched
1977	OECD report is published, determining the relationship between emissions and depositions of sulphur compounds
1979	Convention on Long-range Transboundary Air Pollution (CLRTAP) is agreed
1979	WHO recommends air quality guidelines, setting a standard for the pollution abatement work in Europe
1980s	Forest death from 'acid rain' in Germany, Poland, Czechoslovakia and North America
1985	CLRTAP Protocol agrees 30 % reduction in sulphur emissions
1988	The EU directive on large combustion plants is published, and amended in 1988. These were very efficiently used by Germany against the British opposition to emission controls
1994	Second sulphur protocol, based on the critical load concept that had already been mapped all over Europe

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