From Resource Scarcity to Pollution Problem: The Production and Environmental Impact of a Swedish Alum Works, 1723-1877

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SUMMARY

Wood scarcity at Lovers Alum Works (LAW) restricted the amount of alum produced during a large part of the period of activity (1723-1810s). The increasing local scarcity of wood and the insufficient road network were the main reasons why LAW started to use alum-shale as fuel in the beginning of the nineteenth century. When the fossil energy source replaced wood the short term fluctuations in alum production between different years became much smaller and the production of alum in the region was able to expand. This has been interpreted as an example of how geospheric raw materials enabled the rapid production expansion during the early industrial revolution.

Cadmium and sulphur emissions were estimated from element analysis of the shale and data on the use of shale and other raw-materials. During the shale fuel period (1810s-1877) the emissions of volatile substances such as cadmium and sulphur increased.

Pollution and resource scarcities are two different forms of environmental impact which tend to have different effects at different times in regard to production. Resource scarcity problems tend to have a regulating effect on production while pollution problems tend to lack this self-regulating effect on production.

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1. RAW MATERIALS AND ENVIRONMENTAL IMPACT: AN INTRODUCTION

When seeking for a broad perspective on the environmental problems of today it may be fruitful to study the environmental impacts produced by man and society, and how these impacts have changed over time. In the environmental debate of today 'sustainable development' and 'renewable resources' are high profile concepts. With this in mind it is interesting to investigate how the importance of renewable resources has in tended to decrease during the era of industrialisation, while simultaneously the use of non-renewable resources of fossil or inorganic kind has increased. The increased use of fossil and inorganic raw materials may have been an important factor enabling the rapid expansion of production during the beginning of the industrial revolution. The resulting environmental impact may also have changed as more fossil and inorganic raw materials were used. The aim of this study is to discuss the changing production and environmental impact of a Swedish alum works (*bruk*), Lovers Alum Works (LAW). The period under study is 1723 to 1877. During the eighteenth century LAW used wood exclusively as fuel, but in the beginning of the nineteenth century they gradually started to use alum-shale as fuel. It is interesting to investigate why LAW reduced their use of the renewable resource, wood, and increased the use of a non-renewable resource. In this study we examine the effects from this transition from an organic to a fossil energy source, the effects on the alum production as well as the environmental impact.

In this article raw material is defined as some sort of natural resource adapted by humans. We distinguish between biospheric and geospheric raw materials. Biospheric raw materials are defined as adapted biological material. Geospheric raw materials are of fossil and inorganic origin and are not extracted from living plants or animals but are extracted from the crust of the earth.

E.A. Wrigley and some other scientists have suggested that the wider use of geospheric raw materials enabled the rapid expansion in production during the industrial revolution. During the earlier stages of the industrial revolution the production of various commodities was hampered by the overwhelming dependence on biospheric raw materials. Wood and charcoal were used to provide heat, power was obtained through human and animal muscular labour and local water-power. Accordingly, the magnitude of the early industrial production and the agricultural output was restricted by biological and physical limits that restricted the amount of biomass it was feasible to extract from a given area. We name these biological and physical limits biospheric production capacity. Agriculture, foundries and manufacturing industries were all to a large extent dependent on the same kind of biospheric raw materials, and often competed for them. If one of these sectors expanded it often resulted in inconveniences for the others. The increased use of geospheric raw materials enabled a large, rapid expansion of industrial output because of reduced dependence on the biospheric production capacity (Wrigley, 1962: 1-2, 5)

The expanding use of geospheric raw materials had important consequences for the development of the communication network on land. Most biospheric raw materials are obtained from some kind of extensive areal production. Therefore, general use of biospheric raw materials tends to lead to extensive areal production. When areal production prevails, production as well as the producers tend to be widely scattered. Production as well as consumption tends to take place locally and therefore, the need for large scale transportation on land is limited. However, when the use of geospheric raw materials increased so did the need for long distance transportation on land. Inorganic and fossil raw materials, e.g. iron ore and coal, can only be mined in certain specific places, unlike biospheric raw materials which tend to be extracted over large areas. Because the extraction of the geospheric raw materials is concentrated at certain points the demand for long range transportation on land increases, e.g. you have to transport the coal to the iron ore. As the use of geospheric raw materials increased production tended to become concentrated in a small number of places. Because of the expanding economy and industry it was possible to make larger investments in the development of communications on land (Wrigley, 1962: 3-4, 6-7, 10).

The use of geospheric raw materials increased gradually and to a very different extent in different industries. The time when this slow change took place varied considerably between different sectors. Of course the switch to geospheric raw materials was by no means complete: many of today's raw materials are of biospheric origin. However, the production of biospheric raw materials has been influenced by the development of an extensive communication network and more centralised production. This results from the increased use of geospheric raw materials in some important sectors of industry (Wrigley, 1962: 8).

In this article we distinguish between the concepts 'environmental impact' and 'environmental problem'. Human activity usually results in some kind of environmental impact. However, whether or not a specific form of environmental impact is conceived of as an environmental problem may differ from one time to another. The interpretation of an environmental impact may also differ between various groups in society, and will depend on what more urgent and immediate problems that society has to tackle. In this study we focus on two different types of environmental impact: the extensive use of forests, and heavy metal emissions from alum-shale burning. The extensive use of forests can be seen as an example of environmental impact resulting from the use of a biospheric raw material. If local forest scarcity occurred this might seriously affect the foundries and manufacturing industries as well as agriculture as these were all dependent on the availability of wood. Insufficient forest resources were regarded as a serious problem in eighteenth century Sweden because wood was the dominant construction material as well as the main source of heat. When works and manufacturing industries received governmental permission to start production the Royal Mining Board (*bergskollegium*) decided how much they were allowed to produce. The decision was based on access to labour and the

supply of relevant natural resources in the region (Karlsson, 1990: 26-29, 192, 201-203). The question then arises, ascommented upon by O. Nordström, whether there actually was some forest scarcity in areas densely populated with works, foundries and manufacturing industries. He has studied some iron-works in the southeast of Sweden. A result of his investigation is that the iron-works were not able to produce the amount of iron they were allowed by the Royal Mining Board. The main reason was the low prices for charcoal, that were not adjusted to take account of supply and demand and the bad roads. As a result only the nearest and most accessible forests were used. In the most easily accessible forests the amount of charcoal produced was commensurate with the yearly rate of growth of the forest (Nordström, 1952: 26-43, 127-128).

Alum-shale burning provides an example of environmental impact caused by the use of geospheric raw materials. In contrast to local forest scarcity, the environmental impact from heavy metal emissions often takes effect in the distant future. The transport and leaching of heavy metals in soils are slow processes. Soils have a limited capacity for keeping and containing heavy metals. When this capacity is exhausted heavy metals will be drained through the soil profile towards the ground water. Heavy metal emissions from point sources during the eighteenth and nineteenth centuries are excellent resources for the study of the dynamics of these processes over time. In this study we have chosen to reconstruct the cadmium emissions from alum production.

2. THE ALUM PRODUCTION AT LOVERS ALUM WORKS

Alum is a double sulphate of aluminium with a base, which in the case of Swedish alum is potassium. It had a wide range of uses during the eighteenth and nineteenth century and was of great economic importance (Singer, 1948). Alum was mainly used as a mordant or a pigment when dyeing cloth, but was also mixed in rag paper to bind the fibres together (Geschwind, 1901). The production of alum demanded advanced technology and organisation of work, both being important features of an industrial production system. Therefore one could say that the alum works were the first chemotechnical industries of Sweden. The earliest alum production in Scandinavia was started in Andrarum, Skåne in 1637 and the next establishment was Lovers Alum Works (LAW) in 1723. During the eighteenth and nineteenth century another eight alum works were established in the country (Stoltz, 1934).

The major raw material used in the Swedish alum production was black shales, which were mined in opencast mines with hand tools. The composition of the shale differs between different deposits but some common features are relatively high contents of organic matter and trace substances such as most metals. These shales thus contain stored energy and can therefore burn. The first step in the alum production was roasting of the shale (Figure 1), where some

FIGURE 1. Leaching and burning of shale for production of alum. *Uppfinningarnas bok* part 7 1903 Stockholm (in Swedish), page 343

wood was needed to lighten the shale heaps. After that the shale burned without any further use of wood. The burnt shale was then leached with water to dissolve the alum salt. The most energy-demanding part of the process was removing the water from the leachate and concentrating the alum by evaporation. A large lead pan that contained 8000 litres (a double-pan) was filled with the leachate and heated with woodfuel. To evaporate a sufficient amount of water about 25 to 30 m^3 of wood was needed. In the refinement more water was added and the evaporation was repeated to obtain a reasonably pure alum. The alum solution was then left for some days to form alum crystals. The alum was packed in barrels, each containing about 145 kg, which is the quantity unit used in this paper.

During the later part of the nineteenth century the demand for alum decreased. Paper fabricated of cellulose, not containing alum, started to replace the old rag paper. In textile dyeing, alum was largely replaced by aluminium sulphate produced from other raw materials than the shale. Because of these changes the Swedish shale-based production of alum ceased entirely around the turn of the century.

Large quantities of wood were consumed in the processes of evaporation and refinement, and the alum works kept on using wood as fuel despite the fact that it was known the shale could burn. There is evidence from the eighteenth century that shale was being used as a fuel when burning lime as described by von Linné (1974) from his travels to Öland in 1741. It was also known early on that the use of shale as fuel also could be applied in the alum industry. Bergman (1767) mentions this fact in Proceedings from the Royal Scientific Academy 1767 where he describes methods for production of alum. During the 1770s new smaller pans (single-pans) were constructed at a Swedish alum works, Garphyttan in the Närke province, where the shale could be used as fuel when evaporating and refining the alum solution (Rinman, 1788).

The alum works which are the focus of this study, Lovers Alum Works (LAW), was established as a small experimental plant in 1723 at Degerhamn on the island of Öland (Figure 2). At that location there were large shale deposits, later estimated to about two billion tons (Holmberg, 1930), easily accessible, only covered with a thin soil layer. The wood which was needed as fuel was transported from the mainland since wood was very scarce on Öland. Two years later the alum works was moved over to the mainland because it was considered easier to transport the shale to the mainland than the wood to Öland. So the shale was mined on Öland and brought over to the mainland with sailing-vessels. It was there loaded on to barges and taken up the small Lovers river about 500 metres to the works. This system persisted until 1841 when the production unit was moved over to Öland.

From 1723 to 1810 LAW depended entirely on woodfuel for the energy-demanding processes of evaporation and refinement, and during most of this time four double-pans were used for evaporation and a fifth for the refinement. The woodfuel was delivered by the farmers in the surrounding areas, mainly from within an area of ten kilometre radius. In the alum works' charter from the governmental Royal Mining Board it is stated that the establishment of no other wood consuming works was permitted within the area of the seven parishes surrounding the alum works. The purpose of this arrangement was to prevent competition for woodfuel between different works. From 1810 to 1840 the main part of the evaporation was still carried out in the woodfuel pans, but two new shale pans were constructed around 1810. Instead of roasting the shale out in the open in huge heaps, these new pans made it possible to utilise the shale that needed to be roasted also as fuel. However, a substantial part of the shale that was burnt under the pans could not be used for leaching since the consumption of shale as fuel was much higher than the amount needed for leaching. According to one estimate from the regional mining officer in 1811 (The Regional Mining Officer's letters, investigations and records, 1811) about 50 per cent of the shale had to be disposed of. From 1841, after the reestablishment of the works on Öland, shale alone was used as fuel in evaporation and refinement. The production of alum at LAW ceased in 1877. In this article we refer to these three

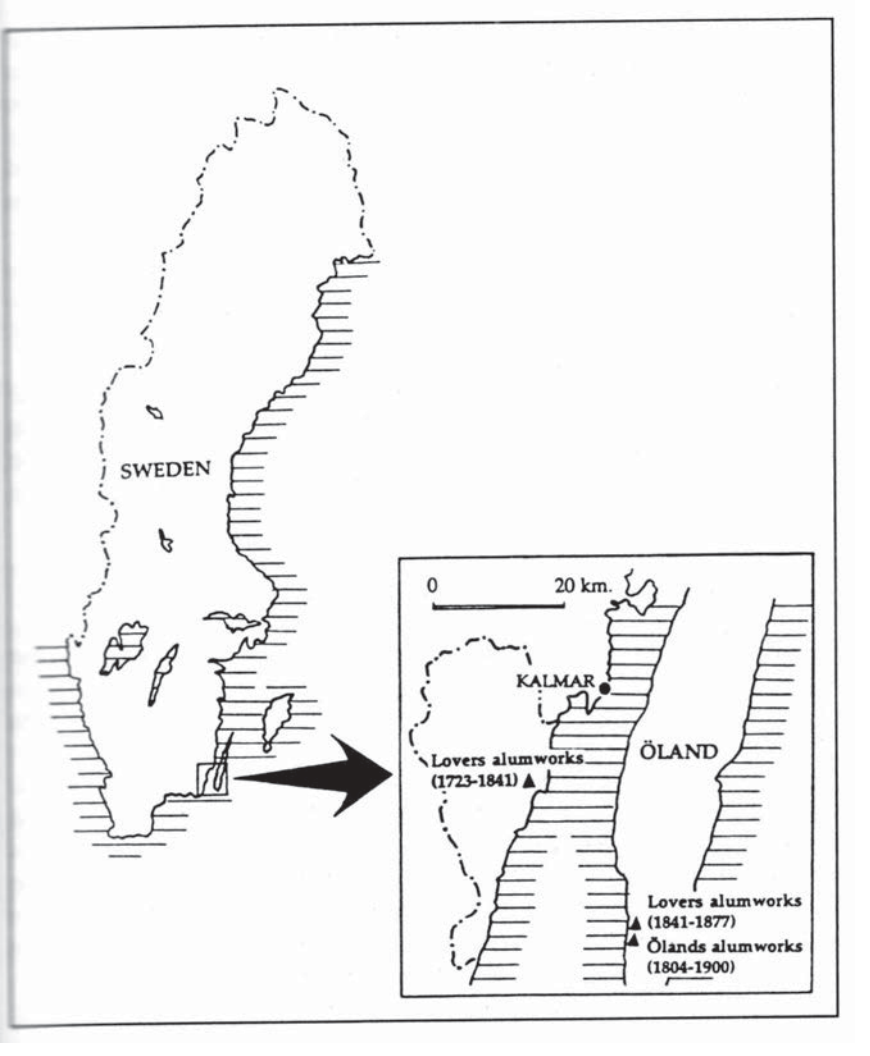

FIGURE 2. The location of Lovers Alum Works. The shale was mined on Öland near the works during the whole period. The seven parish area designated to serve Lovers Alum Works is indicated on the map.

different periods, based on their energy-support system as; (i) the wood fuel period (1723 to 1810), (ii) the transition period (1810 to 1840) and (iii) the shale period (1840 to 1877).

A competing works applied for and was given a charter for alum production in 1804 but the Royal Mining Board laid down the condition that only shale

should be used as fuel. If this condition was violated and any other fuel was used the privilege would be withdrawn. According to the Royal Mining Board this establishment was possible without detriment to others since the shale supply was considered to be almost without limits. Another possible reason for the decision to allow a new works was that LAW had evidently been mismanaged for some years around 1800, and so had not contributed to the public treasury as much as it should have done.

3. FROM WOOD TO SHALE AS AN ENERGY SOURCE

During the period 1810-1841 LAW gradually started to use alum shale as fuel instead of wood. The use of alum shale as fuel had been well known for about one hundred years and therefore some additional factor must lie behind the reduction in the use of wood as fuel during this period. Was this local forest scarcity, the high price of wood or poor road communications?

3.1. Early complaints about local forest scarcity

In 1739, when LAW had been in operation for 16 years the local deputy for the Royal Mining Board made a thorough report on the conditions for alum production at LAW. The purpose was to estimate the pros and cons for alum production, as a basis for taxation.

The surrounding seven parishes were obliged by custom to deliver wood to the alum works. LAW was the only works or manufacturing industry allowed within the region consisting of these seven parishes. The forest resources in this region were inspected by the representative from the Royal Mining Board, the Regional Mining Officer (*bergmästare*). The forest resources were regarded as abundant in some of the parishes, but the road network was often described as insufficient. Slash and burn was common practice. The farmers in some parishes had saw-mills and sold timber and wood to nearby towns and to Öland. The forests within a 2.5-4 km. radius from the alum works were described as largely laid waste. The soil was considered barren, which hindered regeneration. Because of the bad roads most of the wood delivered to LAW came from forests within a 10-15 km. radius. The Regional Mining Officer considered that LAW would encounter a serious lack of wood fuel and high wood prices if the road network was not improved. He suggested that the government should impose a decree with the purpose of getting the farmers to tend the forest more carefully and improve the road network (The Regional Mining Officer's reports and investigations 1739).

During the 1740s the owners of LAW repeatedly complained to the government and the Royal Mining Ministry about lack of wood for fuel at the alum works. One measure that was taken was to employ a forester in order to make it

easier to sue any peasant who violated the laws for forest preservation and the mining acts. The owners of LAW also appealed to the Royal Mining Board to obtain sole permission to buy wood from the seven-parish region. This appeal was refused on the grounds that Öland and the nearby towns should not be left without sufficient wood and timber (Letters to the Royal Mining Board 1744 and the Royal Mining Board's resolutions, 1747).

In a description of Swedish alum works the situation at LAW was commented upon. The author wrote that LAW often lacked a sufficient supply of wood and that the price of wood at LAW had risen by 20% (Sohlberg: 'Descriptions of Swedish alum works', 1758).

The general impression from the relevant written sources from the 1740s and 1750s is that the owners of LAW regarded wood shortage as a serious problem and some of the improvements they tried to make have been mentioned. The reasons mentioned for the lack of wood at LAW was lack of a sufficiently developed road network and local forest scarcity.

3.2. The compulsory obligation to deliver wood

In order to reduce the wood shortage at LAW the local crown-land bailiff (*kronobefallningsman*) outlined the draft of an agreement between the farmers in the seven parishes and the alum works in 1754. This suggested that the farmers should deliver a fixed amount of wood to LAW every year. The price should be fixed without considering the transportation distance. The minimum amount of wood delivered would be based on the tax rates of the individual farms. This agreement did not come into effect until three years later when the owners of LAW had exercised some pressure on the farmers. LAW's owners appealed to the government and the Royal Mining Board with the object of buying the right of taxation for some crown land farmers (*skatteköp*). They also wanted to take over the personal taxes paid by the farmers in order to convert these taxes into a duty to deliver wood to the works. Facing this situation the farmers chose to sign the initial agreement outlined three years before. Some farmers with bad road connections and others who cultivated land owned by noblemen, were exempt from the agreement (grievances from the jurisdictional district Södra Möre in Kalmar county 1769-1771).

The farmers saw themselves as forced into the agreement and tried in various ways to abolish it. Their district representative in the four estate parliament tried at nearly every parliamentary meeting between 1762 and 1829 to get the agreement abolished. The farmers in the region also wrote several official complaints to the government. The main argument was that they had been forced into the agreement. One reason that was often repeated was that some of the farmers now lacked sufficient wood resources for their own use. The farmers also maintained that they were no longer able to fulfil their informal duty to sell wood to the nearby towns and to Öland (grievances 1769-1771 and the Regional

Mining Officer's correspondence with the Royal Mining Board and the Royal Mining Board's resolutions 1758, 1766, 1792, 1829).

The appeals made by the farmers were mostly unsuccessful but the fixed wood price was abandoned in 1766 and from then on the price of wood at the alum works was the same as the official price paid by the government (*markegångstaxa*) (Royal Mining Board resolution 1766).

The agreement with the farmers seems not to have decreased the wood scarcity at the alum works to any large extent, at least the alum production did not increase significantly. The farmers repeated and extensive efforts to abolish the agreement about wood deliveries imply that a local scarcity of wood may have been a serious problem for some of the farmers.

3.3. The requests that Lovers Alum Works should use alum-shale as fuel

The Royal Mining Board permitted a new alum works, called Öland's Alum Works (ÖAW) , to be established on Öland in 1804. This led to extensive protests from LAW and from some of the farmers in the area on southern Öland.

The owners of LAW argued that the wood resources were too scarce on the mainland to permit an additional alum works, although Öland's Alum Works were granted their charter on condition that they use only alum-shale as fuel. On the other hand, LAW argued that the amount of wood needed to ignite the alum-shale was unknown. The owners of LAW also argued that their own charter of privilege stated that they had the sole right to use the shale deposits on Öland. LAW claimed:

> the price of wood is high out of all proportion, and its purchase encumbers the production all too much, and more seriously, depletes the forests for the alum works in a most noticeable way. And who knows if the time will soon come when we ourselves at the old Lovers Alum Works, having economised on the use of wood to the largest possible extent, are compelled to seek out a part of our bed-rock to find a shale which could suitably be used as fuel, or at least with some addition of wood could be used for alum boiling. (translated quotation from memoranda compiled in the Regional Mining Officer's records 1804)

In a separate decree some farmers on Öland expressed fears that smoke from the alum-shale burning would harm agriculture. They also pointed out that starting an alum works on Öland would lead to a large migration of workers and their families to Öland; which in turn would lead to an increased demand for wood. The farmers were worried that the price of wood would rise even further and mentioned that it was already twice as high as further north (memoranda compiled in the Regional Mining Officers records).

At the meeting of the national parliament in 1803 the farmers' representative from the southern part of Öland requested that the government should forbid the establishment of more forest-devastating foundries, works and manufacturing industries in this part of Sweden. He also applied for the farmers on Öland who

lacked forest resources of their own to be permitted to buy wood from the mainland without the usual commercial restrictions. At the parliament gatherings in 1809 and 1812 the farmers' representative requested that LAW should be compelled to use only alum-shale as fuel. As a result the Regional Mining Officer summoned the owners of LAW to a meeting. From the record of that meeting it appears that at that time LAW had three single pans fuelled by alum-shale in use and three additional single pans were under construction. The owners considered it uneconomical to further increase the use of alum-shale as fuel, as to do so they would have to transport shale from Öland to Lovers just to use it as fuel. With the composition of six single pans fuelled by alum-shale and three large wood fuel pans all the shale used as fuel could be used in the leaching process. (LAW's archives and the Regional Mining Officer's records 1811, 1813). Repeated requests from the parliament representatives resulted in a thorough investigation into which mode of production would be least expensive for LAW, the use of wood fuel or alum-shale fuel. The construction of new pans and changes in wage and transportation costs were all taken in to account by the Regional Mining Officer and his assistants. The result of the investigation was that shale was stated to be the cheapest fuel. However, the Regional Mining Officer now estimated that much more of the shale used as fuel could be used in the leaching process than the owners of LAW themselves had estimated in 1811 with the assistance of the Regional Mining Officer. The account books from LAW shows that large quantities of wood were continuously being used. In the Regional Mining Officer's records it appears that conflicts had occurred between Lovers and Ölands Alum Works concerning the purchase of wood from the mainland (account books, Lovers Alum Works and the Regional Mining Officer's records 1814).

It is interesting to note how the farmers' parliamentary representative in 1803 and 1804 tried to stop further establishment of wood consuming works and manufacturing industries. After ÖAW had been established the representative demanded that LAW should be forced to use alum shale as fuel. This suggests that the farmers regarded local wood scarcity as a more important problem than harmful smoke from the shale burning, which had been used as an argument against the establishment of ÖAW in 1804. In the written sources we have studied, complaints about the smoke are very seldom mentioned.

The course of events during the wood fuel period exemplifies Wrigley's arguments concerning different sectors' heavy dependence on the same kind of biospheric raw materials and frequent competition for them. During the wood fuel period LAW tried to increase the amount of wood delivered to the alum works by increased wood prices and by other pressures. This led to conflicts with the farmers and with ÖAW. The farmers on the mainland wanted to decide for themselves how to use their forest resources. The farmers sold timber and wood to the nearby towns and practised slash and burn. The farmers on Öland argued against new wood consuming works and manufacturies because they were afraid that the price of wood might rise further. Government action was guided by an

interest in a large income from the alum production through taxation. The government also had to prevent other trades and branches suffering too much from the alum production. This explains both why the establishment of ÖAW was allowed as well as the extensive measures taken to convince LAW to use alum-shale as fuel.

The governmental actions as mediator between different sectors can be interpreted as examples of a general norm for house-keeping. According to P.-A. Karlsson the housekeeping principle was an economic policy norm during this period. Different institutions in society directed the economy with the aim of production control and restricted competition between different sectors as well as within sectors. The goal was to control the market exchange that would ensure that the just requirements of different sectors and trades were provided for and in addition, that a reasonable price level was not interfered with. The main aim was social stability more than maximising economic good (Karlsson, 1990: 29, 192, 201-203, 206-218 and Karlsson 1989).

3.4. Increasing local wood scarcity during the nineteenth century

The amount of wood delivered from different farmers was accounted for in LAW's book-keeping. In Figure 3 the origin and the amount of wood delivered to LAW from different villages is presented. We assume that most of the wood delivered came from forests owned by farmers in the villages. The farmers may have acted as middlemen but it is unlikely that the middlemen's actions were so systematically carried out that they would influence the geographical pattern of wood deliveries. Four percent of the total amount of wood delivered to LAW remains impossible to connect to a specific location on the maps.

The account books show that the amount of wood delivered varied very much from one year to another, often by as much as 4000 to 9000 cubic metres. Occasionally wood was bought elsewhere outside the region. This wood was usually transported by boat to the alum works. In 1813-1815 this wood cost 25% more than the local wood. The great differences in the amount of wood delivered from specific villages from one year to another suggest that the wood delivering agreement was not followed literally during this period.

Figure 3 shows that the wood delivered to the alum works came from villages further and further away from the alum works. In 1791, 7% of the wood delivered to LAW came from villages outside a 10 km. radius, In 1815, 15% and in 1829, 36% This suggests that the wood scarcity in the region increased during the nineteenth century. Another indication of increasing local wood scarcity is the increasing prices on wood paid at LAW. Between 1790 and 1819 the wood price increased by more than 400% (Lovers Alum Works' account books).

Written sources about the road network are scarce, it is therefore impossible to investigate how the alum works may have influenced the development of the local road network.

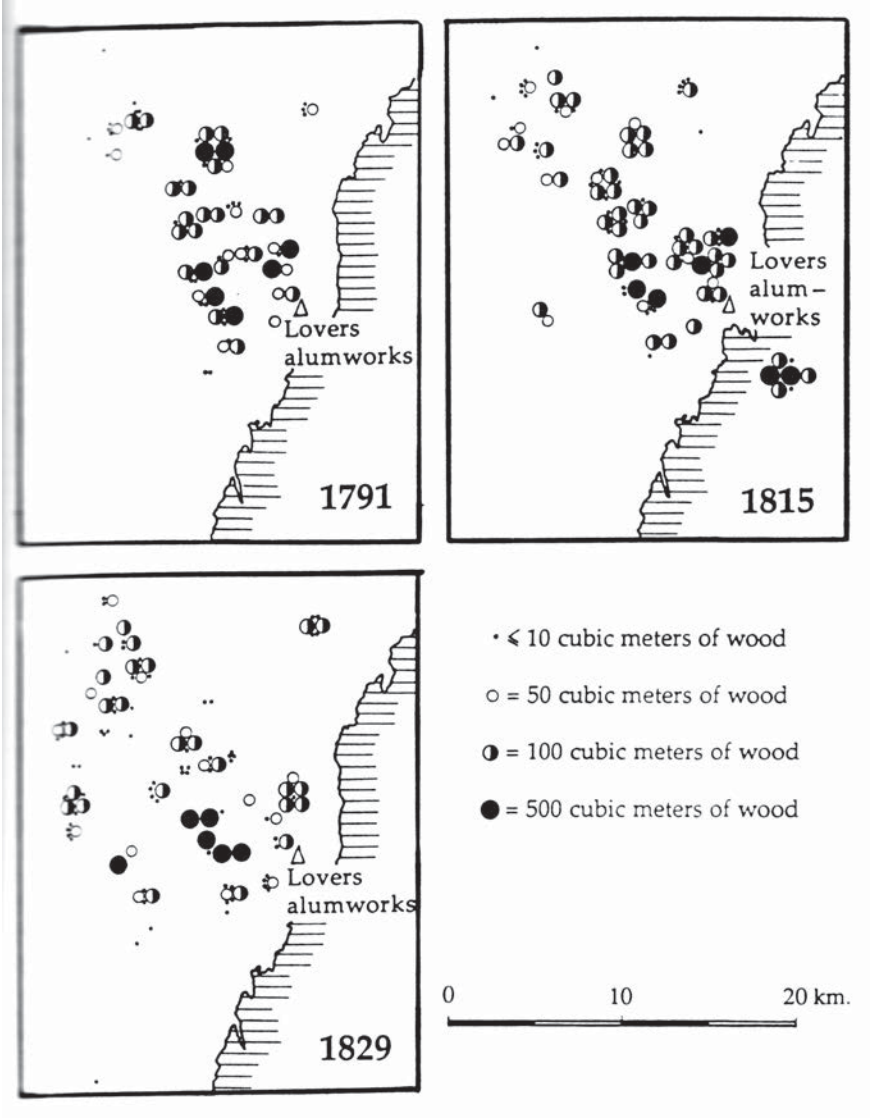

FIGURE 3. Wood deliveries to Lovers Alum Works from different villages during three different years: 1791, 1815 and 1829. In 1815 some wood was bought outside the designated seven parish area. On the map these deliveries have been indicated in the Baltic sea. The total amount delivered was 1791: 6694 m^3; 1815: 8534 m^3; and 1829: 7882 m^3

The increasing scarcity of wood and the inadequate road network are the most likely reasons why LAW successively increased the use of alum-shale as fuel from the 1810s and onwards.

4. EFFECTS ON ALUM PRODUCTION OF A NEW FUEL: SHALE

We have used many different sources in the reconstruction of how much alum was produced. Sometimes we have been able to use the primary source, the company's own account books, and we have used official yearly documents from the regional and local mining officers to the Royal Mining Board to make the record more complete. Other sources that have contributed are a report from a bank inspection of the works in 1762 and one printed source (Killig, 1926). There is no reason to believe that the alum works overestimated their alum production since there was a production tax, a tithe, based on the quantities produced. Instead, it is likely that the alum works tried to withhold information about their production to avoid a higher taxation. The county police commissioner was responsible for the supervision of the alum works' production until 1780, when a local mining officer was appointed and based at the alum works. The main task for the local mining officer was to prevent the alum works from handing over incorrect production figures to the mining authorities. There was also a regional mining officer who was responsible for the supervision of all mining activities in the region. The Royal Mining Board, through their officials, thus had a good knowledge about the quantities of alum produced.

Average yearly alum production does not differ very much between the different periods (Figure 4). Thus, we cannot say that the transition to shale as fuel increased alum production at LAW but the new fuel made possible the establishment of a new alum works on Öland 1804, and so increased the total alum production of the region drastically (Figure 5). This establishment of another alum works illustrates how increased industrial production was made possible when new forms of energy were exploited. A contemporary witness of this development was the Öland vicar Abraham Ahlqvist who in 1822 described the new alum works:

> This Establishment is excellent. On a barren land, where no living creature could subsist, now several hundred people earn their living. The Works consume no forest, the Shale itself from which the alum is leached is used in the furnaces. The Inhabitants of Öland have learned much of this technique. They are already using the Shale assets when burning lime, and the day will come when it will fulfil other needs for wood. Through this Works large sums of money accrue to the Country, and the inhabitants of the area have somewhere to sell their products at a regulated price. Never has the Government with less sacrifice seen an industry with such a large influence both on Common and Private economy so quickly reach perfection. (translated quotation from Ahlqvist, 1822:420-421)

When LAW was established in 1723 they got sole right to alum production in the region but eighty years later the Royal Mining Board allowed ÖAW to take up production. This was possible since the new alum works was going to use shale as fuel and was not expected to compete for woodfuel.

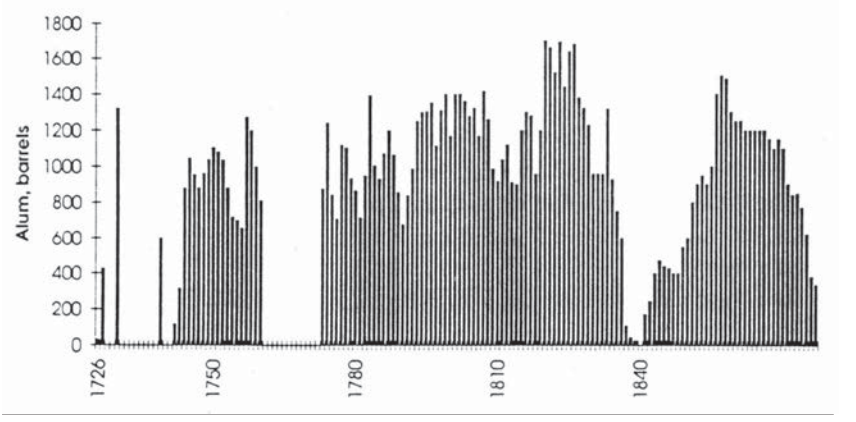

FIGURE 4. Amount of alum produced at Lovers Alum Works during the period 1726-1877. Data are missing for some parts of the 18th century. There was no alum production in 1840 because the alum works moved to Öland. One barrel of alum weighs approximately 144.5 kg.

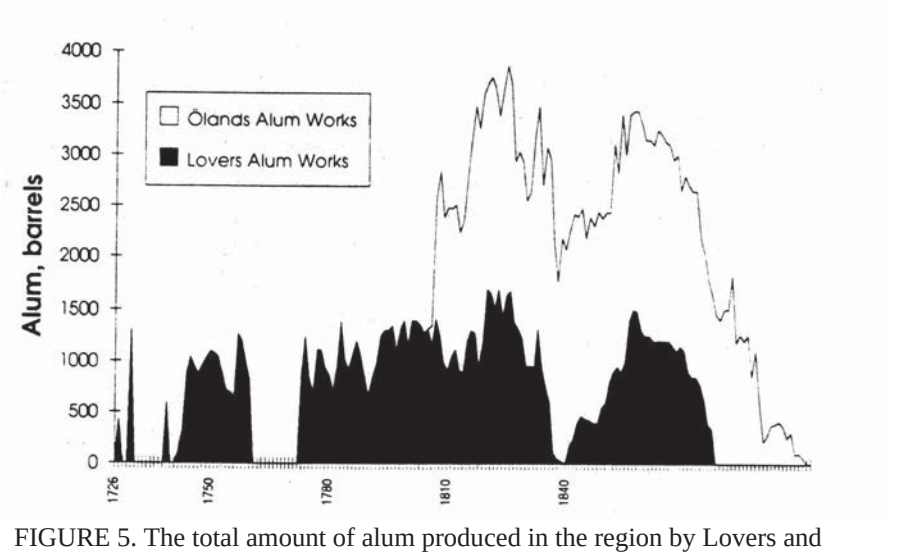

FIGURE 5. The total amount of alum produced in the region by Lovers and Ölands Alum Works during the period 1726-1877. There was no alum production at Lovers alum works in 1840 because the alum works moved to Öland. One barrel of alum weighs approximately 144.5 kg.

In Figure 4 we can see that the yearly alum production during the woodfuel period varied between 700 and 1300 barrels with significant short-term fluctuations. This conspicuous variation also exists during the transition period and cannot be explained by a fluctuating market demand. Our interpretation is instead that the short-term fluctuations depend on problems in the production process and it is likely that woodfuel scarcity was the most significant problem. The coefficient of variation for the alum production during the wood fuel and transition period is 23 % and significantly higher than during the shale period when it was 14 %.

The short-term fluctuations in alum production between different years are much smaller after 1841 when LAW had moved to Öland and was only using shale as fuel. The more uniform production figures from the shale period can be explained by a drastic change in the areal extent and organisation of work for the raw-material support system. During the woodfuel period LAW regularly bought wood from many different farmers up to twenty kilometres distant, implying difficulties in transporting the wood. The alum works tried to establish connections through different agreements with these independent farmers who owned their forests but there were also competitive uses of the fuel-wood. First, there was a local demand for wood both as fuel and building material for the rapidly increasing population but also a sales market in the nearby town, Kalmar. There are some indications that the alum production during this period was restricted to a large extent by the availability of wood which, in turn was a result of local forest scarcity and inadequate land transport communications.

During the shale period the mining was carried out by a specialised work-force who had mining as their main task during eight or nine months of the year. In 1830 eleven men and an unknown number of children formed this work-force. Another fifteen employees were engaged in transporting the shale. In contrast to wood the shale, being a typical geospheric raw material, was produced at a point source thus easing transport. The shale could also be considered as owned by the alum works since they controlled its exploitation through their charter. With shale as fuel the works became independent both from land communications and co-operation with the independent farmers. So, the energy support system of alum production became easier to manage. and this was probably the reason behind the decreasing short-term fluctuations in production.

We expected, according to Wrigley's theory, a significantly increased production of alum when LAW changed fuel from wood to shale. This did not happen but in the theory of industrial expansion there is nothing that says that a single company is the relevant level of study. Instead, Wrigley probably assumes a regional scale in his theory and in this case, the total alum production of the region more than doubled when ÖAW was established. Its establishment was an immediate consequence of the using of a new fuel, the shale. We have found that alum shale as fuel seemed to have made the production process less susceptible to disturbance since it resulted in a less fluctuating production. The reasons

behind it are probably the same as those Wrigley states for industrial expansion as a whole, the spatial distribution of the raw material and its consequences. The organisation of labour and the transport system were both reformed in a favourable way, from the perspective of LAW. During the woodfuel period alum production was restricted by the availability of wood, which was partly a result of biospheric production capacity. When the alum works changed to fossil fuel it was liberated from the limitation of biospheric production capacity.

5. THE ENERGY-SUPPORT SYSTEM AND HEAVY METAL EMISSIONS OF THE ALUM WORKS

When reconstructing the energy use of LAW we have been able to use data from LAW's own account books only for the transition period. For the wood and the shale period we have had to rely on data from an investigation by the regional mining officer in 1816. From these data, conversion factors (Table 1) have been established to be used when estimating the wood and shale consumption of the alum works.

Period	Wood, m^3 consumed per barrel of alum	Shale, tons consumed per barrel of alum
Wood	7.6	3.7
Transition	5.1	5.2
Shale	1.3	6.7

TABLE 1. Estimated consumption of wood and shale when producing one barrel of alum at Lovers Alum Works.

From being solely dependent on wood fuel LAW started to use shale as fuel around 1810 and from 1841 the energy support system was almost entirely based on shale (Figure 6).

Alum shale is formed by transformed sea sediments. These sediments are rich in organic matter and anaerobic. Under such conditions most metals join with sulphur forming metal sulphides. Consequently, these compounds lose their mobility and become incorporated in the sediments. The metal content of these sedimentary shales is therefore relatively high. When the shale is burnt there is a risk that many substances can be emitted to air. In a controlled shale burning Carserud (1982) found sulphur, several halogens and metals such as selenium and zinc in the smoke. Environmentally detrimental substances can accumulate and become concentrated in sediments, in contrast to what happens in living organisms which can discriminate against the uptake of such sub-

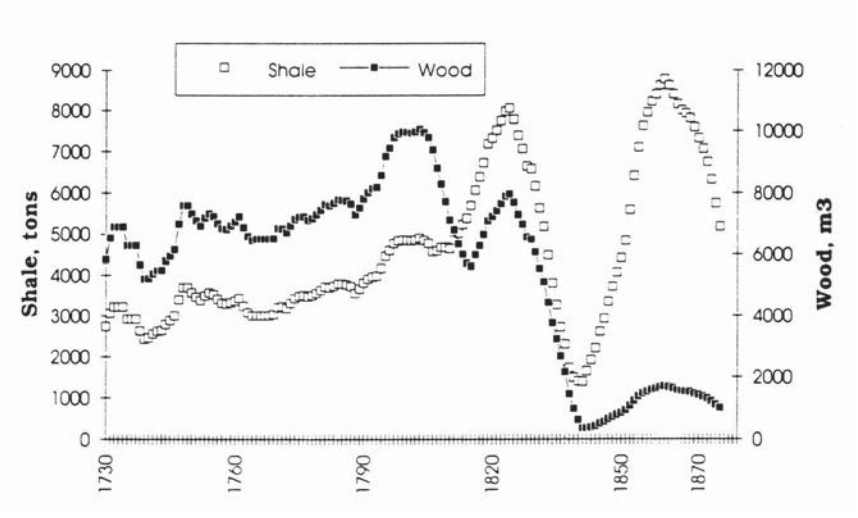

FIGURE 6. Reconstruction of the firewood and alum shale consumption at Lovers Alum Works during the period 1730-1877.

stances. The content of elements, which we today consider environmentally detrimental, is therefore much lower in wood than in alum shale. As an example the cadmium content of wood is about 0.02 - 0.04 mg/kg while the corresponding value for Swedish shales is 2.2 - 7 mg/kg.

The transition from wood to shale fuel thus implied significantly higher emissions of several substances. In this study we have chosen to illustrate heavy metal pollution by reconstructing the cadmium emissions from the burning of shale during LAW's whole period of operation. We use cadmium because it is toxic in low concentrations and has a low boiling-point. Cadmium from the shale has either been emitted to air during the burning or leached out of the shale ashes. In the first case cadmium could have been spread over a vast area, while in the latter case it remained in the immediate surroundings. The proportion that was spread by air determines the range of pollution. The Öland shale contains about 5.8 mg cadmium per kg of shale, and according to our estimates approximately 3900 kg of cadmium would have been emitted from the alum works. 2700 kg of this was emitted on the mainland during the wood fuel and transition periods, while another 1200 kg was emitted during the shale period, on Öland (Figure 7). The contribution of cadmium emissions from ÖAW amounted to about 5700 kg, which put together, means an addition of cadmium to the region of about 9600 kg. The emission and deposition pattern of heavy metals around LAW on the mainland is futher described in Eklund et. al. (1995).

It is obvious that the environmental impact from alum production changed significantly when LAW started to use shale as fuel, since the amount of shale that was burnt almost doubled per produced unit of alum. The emissions of all

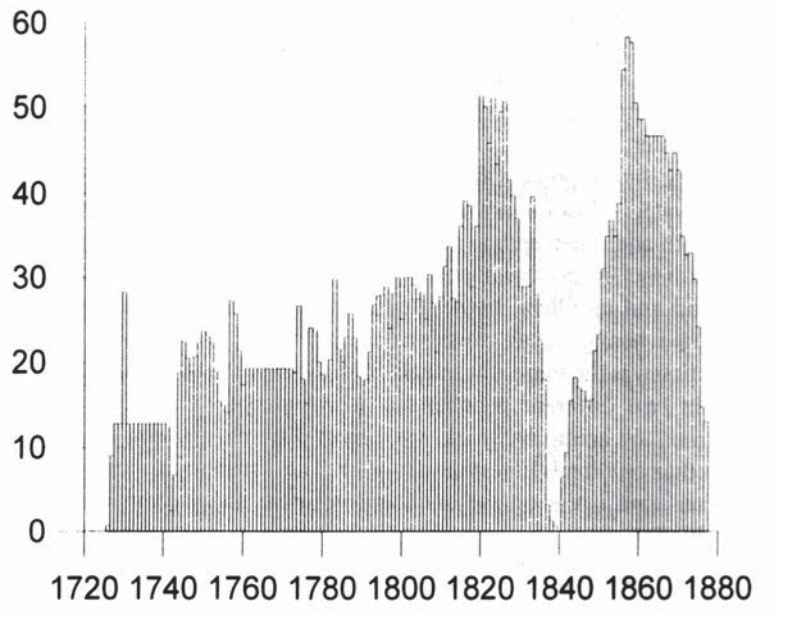

FIGURE 7. Reconstruction of the cadmium emissions from Lovers Alum Works during the period 1726-1877. The reconstruction is based on the yearly production quantities of alum and information about the amount of shale used for the production of one barrel (Table 1). The reconstruction is based on the assumption that all of the cadmium contained in the shale was emitted (5.8 mg/kg).

substances with a low boiling point probably also doubled simultaneously. In the case of cadmium, it is estimated that about 19 g was emitted when producing one barrel of alum during the woodfuel period. During the shale period that amount doubled to about 38 g. About 900 kg of the cadmium emissions from LAW can be directly ascribed to the transition to shale. If the contribution from Ölands alum works is incorporated in the estimate the corresponding figure will be about 6600 kg.

How do these early industrial emissions compare with those of modern industrial production? The 10 tons of cadmium from the two alum works is comparable with the emissions to air from Sweden's main nickel-cadmium accumulator manufacturerer, which emitted about eight tons to air during the period between 1910 and 1974. But, by comparison with Sweden's major cadmium emitter, Rönnskärsverken, which emitted about 270 tons to air from 1940 to 1990, the contribution from the alum works is small. Thus, the emissions from modern production industry are of a different order of magnitude to those from alum production during the eighteenth and nineteenth centuries. In spite of

that, the cadmium content of soils around the alum works is elevated relative to average soil contents, 150 years after the works on the mainland closed down. Furthermore, it is most likely that some of the cadmium originating from the alum production may today be found further down in the soil profiles and in the ground water.

The pollution process from emission of a substance to its appearance in ground water is slow for most metals. Point source polluters operating during the eighteenth and nineteenth centuries are therefore excellent study sites for the long-term dynamics of heavy metal pollution. In this case the alum works on the mainland and on Öland burned large quantities of shale and so contributed significant heavy metal emissions to the region. The raw material in the production was the same, alum shale from the same source, but the burning took place in two different geochemical environments. On the mainland, with sandstone and acidic bed-rock, we expect different patterns of transport and effects than on Ölands limestone bed-rock. The distribution of cadmium and lead in soil around LAW on the mainland is futher analysed in Bergbäck et. al. (submitted).

6. RAW MATERIALS AND ENVIRONMENTAL IMPACT – SOME CONCLUDING REMARKS

Our study has showed that wood scarcity at LAW was a longstanding problem that restricted the amount of alum produced during a large part of the wood fuel period (1723-1810s). When the owners of LAW tried to increase the amount of wood delivered to the alum works this led to conflicts with the neighbouring farmers. Local wood scarcity was regarded as a serious problem by all parties involved. The LAW example shows how the government tried to allot limited wood resources between different users in an appropriate manner. The development of events during the wood fuel period exemplifies Wrigley's thesis about biospheric raw materials having a restricting effect on early industrial production. Some signs indicate that local wood scarcity may have increased at the end of the eighteenth century and the beginning of the nineteenth century. The price paid for wood at LAW during this period increased rapidly. A larger part of the wood delivered to LAW came from villages that was located further away. The inadequate road network was a factor that increased the wood shortage at LAW, since only a small part of the region designated for wood deliveries was actually involved in supplying the necessary wood. According to Wrigley inadequate land communications were at least partly a result of an economy based on domestic production and the extensive production of biospheric raw materials. The increasing local scarcity of wood and the inadequate road network are the most likely reasons why LAW started to use alum-shale as fuel. In terms of the

environmental debate of today, the events during the wood fuel period can be characterised as an unsustainable use of a renewable resource.

Alum production at LAW did not increase as a result of the switch to a fossil energy source, but the large fluctuations in the amount of alum produced from one year to another that existed during the wood fuel period did decrease during the shale fuel period (1841-1877). Dependence on a large number of farmers for delivery of wood to the alum works ceased. The shale fuel was mined by a small number of wage-earners and the transportation distance was short. Thus the owners of LAW got increased control of all the stages of the production process. It was possible to increase the total amount of alum produced in the region when the fossil energy source started to be used. The establishment of ÖAW can be seen as an example of Wrigley's arguments that geospheric raw materials played a large part in enabling a rapid industrial expansion.

During the shale fuel period the emissions of substances such as cadmium and sulphur increased. LAW's change from a biospheric fuel to a geospheric fuel resulted in a changed environmental impact. The alum works' use of wood decreased and the emissions of polluting substances increased.

As was mentioned in the introduction we have chosen to focus this study on two different kinds of environmental impact: extensive use of wood resources and emissions of cadmium. We have chosen these as examples of environmental impacts of two different kinds: local wood scarcity can be seen as an environmental problem of the resource scarcity type, while heavy metal emissions can be regarded as an environmental impact of the pollution type.

Local wood shortage was regarded as a serious problem during the 18th and 19th century since wood was the dominant building material as well as the dominant source of heat. The example of LAW shows how the government tried to allot forest resources between different users. In addition the LAW example also shows how local wood scarcity considerably affected the amount of alum produced over a long period. Environmental problems of resource scarcity type tend to have a regulating effect on production, because production is immediately affected by the supply of the raw material in question.

This study has provided few examples of pollution problems noticed by the people living in the area during that time. Occasionally the farmers complained that the smoke harmed the growing crop but they were not able to prove that the smoke really had a harmful effect on agriculture. These few complaints did not affect the alum works' or the government's action. Of course the heavy metal emissions were not regarded as a problem at that time. The smoke problem and the local scarcity of wood at LAW illustrate a general difference between pollution problems and resource scarcity problems. Wood scarcity had an immediate and limiting effect on early industrial production. In contrast, the problems connected with the smoke did not affect alum production. The effect of the smoke on the nearby farmland is an example of effects affecting another

line of business. Possible negative effects from the smoke would have appeared later and thus a connection was difficult to prove. Therefore, no action was taken. Pollution problems mainly result from the production of various commodities or from the consumption of commodities. Some kind of accumulation in nature has to take place before a pollution problem occurs. Accordingly, pollution problems tend to become apparent later than the actual time when the emission occurred. Thus, environmental impact of pollution type tends not to regulate production, consequently pollution problems often lack the self-regulating effect on production that resource scarcity problems tend to have.

Local wood scarcity consists of the lack of a biospheric raw material. The emission of heavy metals is a form of environmental impact resulting from the use of a geospheric raw material. The LAW case exemplifies how the use of different types of raw materials tends to result in different kinds of environmental impact.

Biospheric raw materials are usually produced by some kind of extensive areal production mode that is often associated with a pattern of scattered localisation of refinement and consumption. The biospheric production capacity limits the amount of biospheric raw materials it is possible to extract from a given area. Waste and by-products of biospheric origin are generally more easily decomposed in nature because they are naturally occurring in abundance in the environment. All this put together explains why an extensive use of biospheric raw materials tends to result in environmental problems in the form of resource scarcities.

In the introduction it was mentioned that the use of geospheric raw materials is not restricted by biospheric production capacity. Geospheric raw materials are extracted from small specific areas, leading to more concentrated production and consumption. Waste and by-products of geospheric origin are more toxic and resistant to decomposition than substances of biospheric origin because they are less abundant in nature. Put together, this explains why extensive use of geospheric raw materials results in environmental problems in the form of pollution.

To conclude we state that if the use of biospheric raw materials results in some kind of environmental problem it tends to be of the resource scarcity type. In contrast, if the use of geospheric raw materials results in some kind of environmental problem it tends to be in the form of pollution problems.

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REFERENCES

From the National Archives, Stockholm:

Popular greviances from Kalmar county to his Majesty.
The archives of the Royal Mining Board. Draft letters.
The archives of the Royal Mining Board. Charters and resolutions.

From the Provincial Archives, Vadstena:

The archive of the eighth mining district. Letters, investigations and records.
The archive of the eighth mining district. Letters from his Majesty and the Royal Mining Board.
The archive of the eighth mining district. The regional mining officer's annual reports to the Royal Mining Board.
Lovers Alum Works account books 1790-1877.
Ölands Cement archives. Copies from Andrarum Alum Works archive.

Printed sources

Ahlqvist, A. 1822. *Ölands historia och beskrifning. Första bandet.* (In Swedish)
Bergbäck B. Eklund M. Lohm U. Duration of soil cadmium and lead pollution from historical alum production (submitted).
Bergman T. 1767. *Förslag att förbättra alun-luttringen. Kungliga vetenskapsakademiens handlingar.* (In Swedish)
Carserud L. 1982. *Environmental geology of mining. An example from a shale processing industry*. Lund.
Eklund M. Bergbäck B. Lohm U. 1995 Reconstruction of historical cadmium and lead emissions from a Swedish alumworks 1726-1840. *The Science of the Total Environment* **170**.
Geschwind L. 1901. *The manufacture of alum, the sulphates of alumina and iron*. London.
Holmberg B. 1930. *Skifferundersökningar VI. Ingeniörsvetenskapsakademiens handlingar*. Stockholm. (In Swedish)
Karlsson P-A. 1989. Housekeeping ideology and equilibrium policy in eighteenth century Sweden. Socio-economic theory and practice prior to the market society. *Scandinavian Economic History Review* **2**.
Karlsson P-A. 1990. Järnbruken och ståndssamhället. Institutionell och attitydmässig konflikt under Sveriges tidiga industrialisering 1700-1770. *Jernkontorets Bergshistoriska Skriftserie* No. 25. Stockholm. (In Swedish)
von Linné C. 1974. *Ölandsresa förrättad 1741*. Stockholm. (In Swedish)
Nordström O. 1952. *Relationer mellan bruk och omland i östra Småland 1750 - 1900*. Lund. (In Swedish)
Rinman S. 1788. *Bergwerckslexicon del 1*. Stockholm. (In Swedish)
Singer C. 1948. *The earliest chemical industry. An essay in the historical relations of economics and technology illustrated from the alum trade*. London.
Stoltz E. 1934. *De skandinaviska alunbruken*. Daedalus - Tekniska muséets årsbok. (In Swedish)
Wrigley E A. 1962. The supply of raw materials in the industrial revolution. *The Economic History Review* **15**.