FOREST EMERGY BASIS FOR SWEDISH POWER IN THE 17th CENTURY

by

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Preface

This study is a joint effort by a forester, a historian and two systems ecologists. We have all contributed with our special knowledge with the aim of presenting a systems overview of a dynamic epoch in Sweden's history, "Stormaktsväldet", which we here may call "The Swedish Baltic Empire in the mid-17th century".

The special feature of the study is the quantitative assessment of the benefits and sacrifices of Sweden's exercise of power, using systems theories and methods for measuring the flow of energy, matter and information. We think that this study presents a more comprehensive and perhaps truer picture, from a biophysical perspective, of the balance between benefits and sacrifices for the Swedish nation, its military operations and its exchanges with other European States than has been debated in the past.

There are probably few states, if any, for which such good and coherent records are available from a period now 350 years in history, an opportunity we make use of in this interdisciplinary work. It is our hope that the study will contribute to systems approaches and encourage scientists of different expertise to similar efforts. For those who are now shaping the future of humanity we believe that the lessons to be learned from historical events through such approaches will be of much greater value than a fragmentary and sectorial knowledge.

Ulf Sundberg June 1994
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Abstract

Sundberg, U,[1], Lindegren, J.[2], Odum, H.T.[3] and Doherty, S.[3] [1]Department of Operational Efficiency, Swedish University of Agricultural Sciences, S-776 98 Garpenberg, Sweden, [2]Department of History, Uppsala University, S-753 10 Uppsala, Sweden, and [3]Center for Environmental Policy, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida 32611-2013, USA). Forest emergy basis for Swedish power in the 17th century. Scand. J. For. Res. Suppl. 1 (1994).

Sweden's rise from relative obscurity to become the most powerful nation in northern Europe during the period 1560–1720 was based on its prosperous metal industry and on tar production. The study addresses this period of history from an energy perspective, assessing the exchange of goods and services between Sweden and the rest of Europe in trade and warfare. In a first step the resource use for these flows, mainly forests, ore, waterpower and people, is estimated in physical units such as volume, weight and power. In the next step the flows are quantified in solar energy Joule (solar emjoule, sej) using transformities for each unity of input. The transformity is the solar emergy required to generate an object. In the trade Sweden exported annually about 25% more emjoule than what was imported. If the resources used for the warfare are included the outflow was about 2.4 times larger than the inflow. If some long term influences on the Swedish economy are included, a more balanced account of costs and benefits is suggested. Each author gives in the summary some remarks from his special perspective.

Key words: energy, emergy, power, forestry, metal industry, tar, history, thirty years war, ecological economics.

Introduction

Theories on the causality of history are many, some involving roles of great persons, key information, timely innovation, random factors, resources, and especially energy. In fact, all of these have a role. In recent years whole systems views of humanity and nature have suggested ways to integrate the diverse factors contributing to the great movements of history. In this paper facts and theories concerning Swedish power in the mid-17th century were combined with an energy systems overview. Then an effort was made to evaluate these factors with a common measure, the SOLAR EMERGY.

EMERGY, spelled with an "M" is the prior work required to make a product or service, expressed in units of one kind of energy, in our case solar energy.

The theory that relates causal importance to EMERGY follows: Items that require much for their production are not long used unless they have effects commensurate with what was required. Therefore in self-organizational processes, impact and contribution become proportional to their EMERGY formation requirements. The hypothesis of our work is that economic and military power follow from the rate of production and use of EMERGY.

Outline and Methods

We will first present an overview of the Swedish Baltic Empire in the mid-17th century in order to orient the reader to this time period. A discussion of Sweden's rise to power and a physical account of its resource base is presented. The EMERGY analysis follows. First we evaluate the annual rate of EMERGY use in mid-17th century Sweden which includes that contributed by renewable energy sources, supporting forest production and that being contributed by non-renewable sources, principally mining of metal ores, as well as imports. Estimates are made for the EMERGY supporting the currency of this period, the Riksdaler. The index of EMERGY/Rdr is a measure of the real buying power of the silver coin and represents the EMERGY supporting paid labour. Because much of the work by humans during this period was unpaid, annual EMERGY-use per capita was also used to assess general labour. EMERGY/Rdr was estimated for Denmark as well in order to evaluate the buying power of the Riksdaler in a country with which Sweden traded. These ratios are used to evaluate the trade and other monetary exchanges with the outside world.

These assessments are then used to evaluate the impacts of trade and overseas military operations during the Thirty Years War. Inputs to military operations include the contributions coming from Sweden and the much larger proportion of military support coming from allied states and the occupied lands. Possible gains from these war efforts, such as acquired territories and net immigration, are considered from an EMERGY perspective. Subsector analyses of EMERGY supporting the industries of copper, iron and silver mining and tar production are then given. Our paper closes with general conclusions, a discussion on EMERGY and energy analysis, and individual remarks by the authors drawn from their particular expertise and contributions. A detailed account of several of these estimates is presented in the Appendices.

As part of the methodology of evaluating EMERGY flows, raw data are multiplied by SOLAR TRANSFORMITIES, defined as the SOLAR EMERGY per unit available energy. Solar transformities measure the position in energy hierarchy. The higher the solar transformity, the more resource is required for its production or replacement. Solar transformities and indices of SOLAR EMERGY per unit mass for some resources assembled for this study are given in Table 1. Some of these are cited from other studies; most originate from the national EMERGY evaluation and subsector evaluations of copper, iron, silver and tar in this study. These solar transformities and those calculated for classes of labour are then used to address larger questions concerning military and general trade balance.

Table 1. *Solar transformities and solar EMERGY for other units used for EMERGY evaluations in this study*

Note	Item	SOLAR EMERGY per unit
1	Direct solar insolation	1 sej/J
2	Precipitation used	1.82 E4 sej/J
3	Hydropower	2.0 E4 sej/J
4	Forest wood	4000 sej/J
5	Horses, ox	1.0 E5 sej/J
6	Charcoal	1.8 E4 sej/J
7	Tar and pitch	2.3 E9 sej/gram
8	Timber for ships	3.2 E14 sej/tonne
9	Copper ore	1 E9 sej/g
10	Copper as exported	51.3 E9 sej/g
11	Iron ore	1 E9 sej/g
12	Bar Iron as exported	10.2 E9 sej/g
13	Silver ore	5 E9 sej/g
14	Silver, coins as exported	1.4 E12 sej/g
15	Bronze cannons, guns, ammunition	6.3 E16 sej/t
16	Ships	13.3 E18 sej/ship
17	Soldiers	8.0 E16 sej/soldier
18	Human labour	4.75 E6 sej/J
19	Swedish services	373 E12 sej/Rdr
20	Danish services	120 E12 sej/Rdr

1 By definition; 1 solar joule = 1 solar emjoule.
2 Use defined as evapotranspiration; 50% of rainfall. Solar transformity is the quotient of global solar emergy and Gibbs free energy of precipitation over land (Odum 1992).
3 Geopotential emergy of stream flow estimated for 2nd order stream (world average is 27800 sej/J; Odum 1992) derived from relation of stream order and transformity (Diamond 1987).
4 Solar emergy supporting forest production in Southern Sweden (from Doherty et al. 1992).
5 Annual emergy of forage production = 3.6 E14 sej/ha/yr (Table 6, item 1); (3.6 E14 sej/ha/yr) (2 ha/horse) / (365 d/yr) / (0.5 kW animal power/day) / (10 hr/d) / (3.6 E6 J/kWh) = 1.0 E5 sej/J.
6 From study of charcoal production in 18th century Sweden (Sundberg et al. 1991).
7 Subsector study, Table 9.
8 Estimate for upgraded timber; considered 2 times wood standing in forest to include human services with estimate for hardwood (2 times solar transformity for spruce/pine in Sweden; Doherty et al. 1992): (8000 sej/J) (2) (2 E10 J/t) = 3.2 E14 sej/t. See also Appendix 3.
9 Solar emergy per gram for copper ore formation processes of the earth (Odum 1992).
10 Subsector study, Table 10.
11 Solar emergy per gram for iron ore formation processes of the earth (Odum 1992).
12 Subsector study, Table 11.
13 Solar emergy per gram for silver ore from turnover rates of volcanic rocks (Odum 1992).
14 Subsector study, Table 12.
15 Estimate for upgraded metals; considered 2 times mean of solar transformities for copper and bar iron (items 12 and 14) to include human services: (mean 3.1 E10 sej/g) (2) (E6 g/t) = 6.3 E16 sej/t.
16 Emergy of ship timbers plus estimate for construction labor (see Table 8, item 5).
17 Annual emergy-use per capita multiplied by mean age of males sent abroad (see Table 8, item 7).
18 Emergy supporting work by humans considered average emergy used per capita (Table 6, item 7) divided by metabolic expenditure: (4.0 E15 sej/p-yr) / (365 d/yr) / (0.08 kW man power/day) / (8 hr/d) / (3.6 E6 J/kWh) = 4.75 E6 sej/J .
19 See Table 7, item 5.
20 See Table 7, item 7.

Abbreviations used in this report:
Rdr = Riksdaler
sej = solar emjoule, the basic emergy unit of measure
ST = solar transformity, defined as solar emergy / energy (sej/J)
En = stands for 10 raised to the power of "n" = 10^n

A History of Sweden as a Great Power

THE RISE OF THE EARLY MODERN STATE

At the middle of the fifteenth century a new type of state evolved in France. This state was founded on an ability to levy centralized taxes on its own population. The taxes were legitimized by wars against foreign powers. The invention of a foreign enemy took place during the Hundred Years War when gradually the war was transformed from one between different feudal princes of the old kind into one were the King of France was fighting the King of England and at last to the point when France was at war with England. The last of these phases was heavily facilitated by the efforts of Joan of Arc and her crusade to liberate France from English oppression.

However, the crucial point in the development took place after the war was concluded. Then Louis XI, King of France, managed, against common decency according to his contemporaries, to keep the army and also strengthen it, although there was peace. The existence of a standing army necessitated, of course, the centralised taxation and the war-taxes of the previous era in this way became permanent. In its turn the standing royal army had to have permanent wars against ulterior enemies or at least a permanent threat of war. With this development the classical feudal power structure broke down. In its wake followed a centralized state. Both the threat that France and her standing army posed to her neighbours and interior reasons led very soon to the creation of a number of similar states. The interior reason being the same as in France, namely that the agrarian crises of the late Middle Ages had led to a heavy drop in the feudal rents. The lords in France and the rest of Western Europe were unable to regain what they had lost, because the depopulation due to the Black Death and a number of recurring outbreaks of plague had led to a situation in which the competition between the lords to get peasants on their land made it impossible to raise the rents to the old level. It was this situation that was utilized by way of centralized state taxation. The new state must partly be regarded as an economic association of the feudal lords, by means of which they were able to regain in the form of taxes and subsequent salaries what they had lost to their peasants due to the competition.

Roughly speaking the situation was pretty much the same in all of Western Europe. But in Eastern Europe another solution of the problem with the falling feudal rents had been adopted. There the competition had been met not by organizing on a grand scale, but by developing a new institution that, at least in theory, stopped all competition between the lords. This institution was the famous second serfdom, that was introduced almost universally east of the river Elbe in Germany. In these parts of Europe there were no social and economical motives to organize states of the French type. On the contrary, centralized states would mean that the lords had to give away some of their incomes to the state for further redistribution, because there was nothing more to be had from the peasants.

Sweden was situated in an area where her neighbours almost entirely were made up by this kind of Eastern power, where the structure remained about the same as it had been in the Middle Ages. The military capacity of these powers was founded on the royal domain and its size and on the ability to make use of old military obligations, for instance the famous szhlachta in Poland. In many respects even Denmark must be regarded as an Eastern power. There the competition for peasants partially had been overcome with the introduction of the vornedeskabet, which hindered men from moving from one estate to another. However, thanks to the reformation the royal domain was huge, consisting of about 50 percent of the land. For a long time this, together with other incomes such as the famous Sound toll, made the Danish king very rich, whose economic capacity could be used, when necessary to buy military capacity. But, nevertheless, to a large extent the medieval power structure survived well into the seventeenth century. In reality, for instance, the king could only control about half of the incomes of the royal domain because much of the production was still subsistence based, outside the monied economy. In one respect, however, the king was a modern prince, and he had full control over the church.

During the reign of Gustav I (1523–1560), Sweden developed along the same lines as Denmark. With the Reformation the King began to establish a grip over the Church and its ideological apparatus. However, the grip was by no means firm at this time. Likewise as in Denmark, the royal domain expanded dramatically due to the confiscation of the estates of the Catholic church. King Gustav I, like his predecessors, was, however, unable to introduce a royal taxation of the modern kind. He could not introduce the so called *extraskatter*. The problem with these kinds of taxes was that they were only acceptable to the peasants in case of war or the coronation of the king, marriage or burials in the royal family. Of course the different kinds of events in the royal family were occurring too seldom and irregularly to enable the king to establish any permanent structures whatsoever, based on these taxes. On a number of occasions Gustav I tried to levy taxes for other reasons. But the response was always the same: a peasant uprising of some kind. Gustav I learned the same lesson as the princes before him had learned in all of Scandinavia and most of Europe; that you could not impose taxes on the population if they were not regarded as legitimate. And the only legitimate reason was war.

SWEDEN BECOMES AN EARLY MODERN STATE

Symbolically a new era of Swedish history began in June 1561. A Swedish troop landed in Tallin (Reval), invited by the burghers of the town and the knights of Estonia. Soon this led to a series of wars against virtually all of Sweden's neighbours. The rather insignificant Swedish military establishment began to grow rapidly as it was financed by a royal war-taxation. The *extraskatter* became a permanent feature of Swedish fiscal life during the reign of Erik XIV, who thereby almost over night succeeded where all his predecessors had failed. From his time and onward, Sweden had a substantial standing army at its disposal, which was not the case in either Denmark or Poland (Fig. 1).

The failure of earlier Swedish princes had its roots in the fact that Sweden did not have any serious enemies, and it was practically impossible to attack Sweden. For one thing only small troops could subsist in the country, due to poor agricultural conditions, small harvests, limited acreage and a thin and very scattered population. There was no point in attacking because there was nothing to be gained in Sweden. In the absence of enemies, the princes more or less were bound to fail. However, the Swedish small-scale involvement in Estonia and other actions provoked Russia, Poland and eventually Denmark to attack Sweden, and thereby a number of enemies were made during the next 160 years.

To begin with the wars were relatively small, involving rather small troops. The foreign wars were during the reign of Erik XIV, Johan III, Sigismund I and Charles IX interwoven with very serious interior troubles — at times outright civil war. During this time the centralization process was temporarily checked. The government's grip over the Church was lost to the priesthood, as religion in different forms was used as the ideological foundation of the competing political factions. Even so, the war and its requirements brought about important changes in Swedish society.

The first need of the early modern warfare was "money, money and still more money" as an Italian commander had told Louis XII, King of France, in 1499. The main problem of Sweden was that there was very little money to get, because Swedish production was mostly subsistence, and Swedish agricultural products were difficult to sell on an international market. With little or nothing to sell, the influx of money was small. As money had to be used to hire troops, pay them and procure weapons, ammunition and clothing,

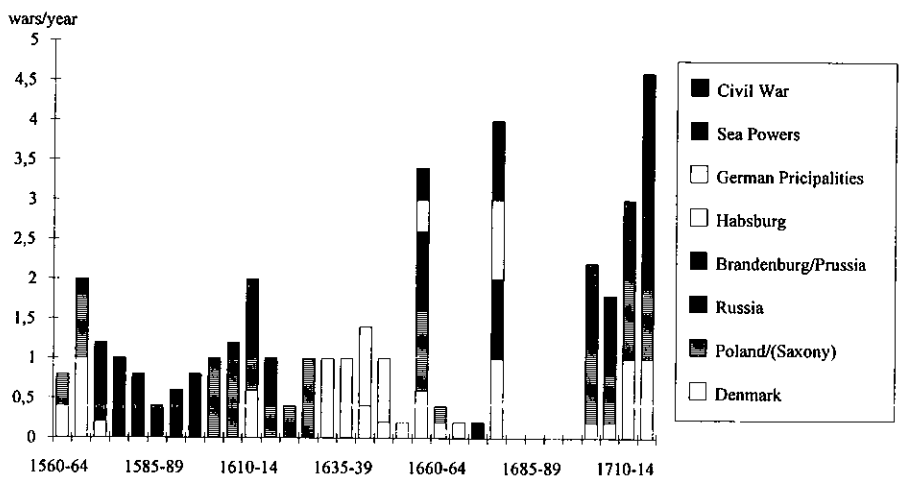


Fig. 1. Sweden's wars 1560–1719 (annual average)

the war coffers had to be reasonably well filled one way or another. At the root of the problem was that there was a contradiction between the prevailing type of production and the needs of the early modern state. The state needed money, gold and silver, but the peasants produced "hens and eggs", as stated by Count Per Brahe, Steward of the Realm.

This contradiction was common to most of the early modern states. To solve it bullionistic theories — the very basis of mercantilism — was developed and even more important: bullionistic policies were pursued. The goal was to acquire as much money (gold and silver) as possible at the expense of one's neighbours. Contrary to the criticisms of some economists, such as Eli Heckscher (1935), this may have been very sound policy at the time, considering the nature of warfare and the general consumption needs of the early modern states.

Prior to the ascension to the throne of Gustav I the problem had already begun to be recognised. It became much more acute when the reorganization of the state began to take place. Facilitated by the steep rise in agricultural prices on the international market during the sixteenth century Gustav I conceived of a method to transform part of the Swedish production into money. Around 1540 the so called *kronohandels* (crown trade) system was established. This meant that the taxes in kind, paid by the peasants of Sweden and Finland, were centralized to a number of depots (varuhus) and then sold by crown officials on the international market. The crown then gained international hard currency, (*Reichsthaler*, *Riksdaler*), silver, gold or commodities, which could only be bought if you had access to hard currency. As can be seen the problem of the state in some ways resembled the trading problems which the Soviet Union had.

However, Swedish agrarian production was comparably inefficient and it became more and more difficult to compete on the international market. At the same time the rise in the prices was checked, which of course also led to increasing problems for the *kronohandels* system. All this was accompanied by acute financial problems. The wars of the 1560s soon had emptied all the state coffers and the situation during the 1570s was even more desperate. At this time — during the reign of Johan III — there was a shift in the economic policy. Instead of trying to compete on the international market with agrarian products Johan directed these and other resources towards the mining and metal industries (Fig. 2). This new policy, which also was followed by his successors on the throne, eventually paid out far beyond every expectation. This success story was the outcome of not only a planned effort, but also by favourable international circumstances. However, King Johan himself did not live to see the triumph of his policy, nor did the following two kings.

SWEDEN AS A 'MILITARY STATE'

If 1561 is regarded as a turning point in Swedish history the same is true of 1617. Even more so, because the upheavals of 1617 were felt at the time and not just recognisable in hindsight. In 1617 Sweden gained a peace with Russia and had for once not a single war going on. However, at the same time as the peace treaty was concluded new plans were laid

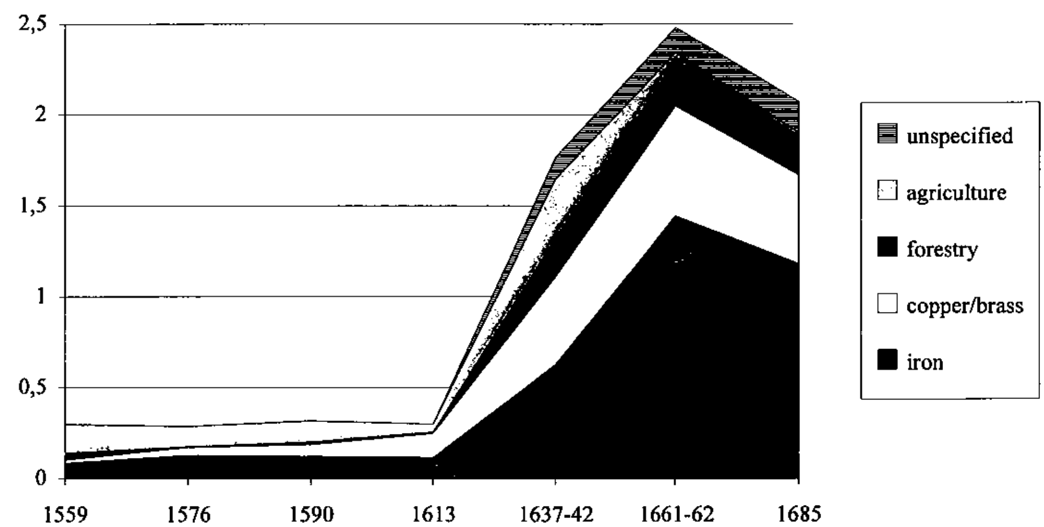


Fig. 2. The value and composition of Swedish exports 1559–1685 (million Riksdaler). Source: Lindegren 1993, p 109.

down. According to these plans Sweden ought to have an army of 26,000 men, although she had only managed to maintain about 15,000 in the preceding war years. But even more sinister than the plans was the reality. After only a couple of years the army reached 40,000 men. For a long period to come the proportion of Sweden's population in arms was higher than anywhere else in Europe (Fig. 3).

The plans and their executions were quite astonishing. They cannot be regarded as a response to threats posed by any of Sweden's neighbours. In fact a couple of years earlier the politicians in Denmark, after the peace with Sweden at Knäred in 1613, reached the conclusion that that country needed a standing army of 4,000 militia men — not a particularly aggressive plan for the future.

But the Swedish plans were, to echo the words of the King, albeit at a later time: what we do not have ourselves we can take from our enemies. The new imperial military policy was in itself an extraordinary achievement of the young King Gustav II Adolf When he ascended to the throne after his father Karl IX he had almost everything going against him. His inheritance was rather impressive: wars with Denmark, Poland and Russia, a more or less total break with most of the Swedish nobility and serious problems with the Church. Many of these problems of course emanated from the fact that his father had usurped the throne not only putting aside the rightful king — on religious grounds, he was a Catholic and according to the *Uppsala möte* of 1593 the Swedish King had to be of the right Protestant confession — but also putting aside the next in line. These people were sons of a usurper, Johan III, who had a rightful heir. Luckily for Gustav II Adolf, this man died in Russia in 1607, where he had been invited by the Tsar. Of course a rightful throne pretender living at one's court was an important pawn in the international politics. But the two most damaging things to Gustav II Adolf's rule was the strife with the nobility and the Church.

By capitulating to the demands of the nobility, accompanied by a policy of reconciliation and declaring the country's adherence to *Uppsala möte*, Gustav II Adolf solved his main problems. Many of the dynastic problems were solved by the timely demise of his uncle, Duke Johan of Östergötland, and his brother Duke Karl Filip. Because of all this, Gustav II Adolf gained the position as a leader of a politically and ideologically united state; a position that none of his predecessors had ever had. Gustav II Adolf utilized his position to sell an extremely expansionist program.

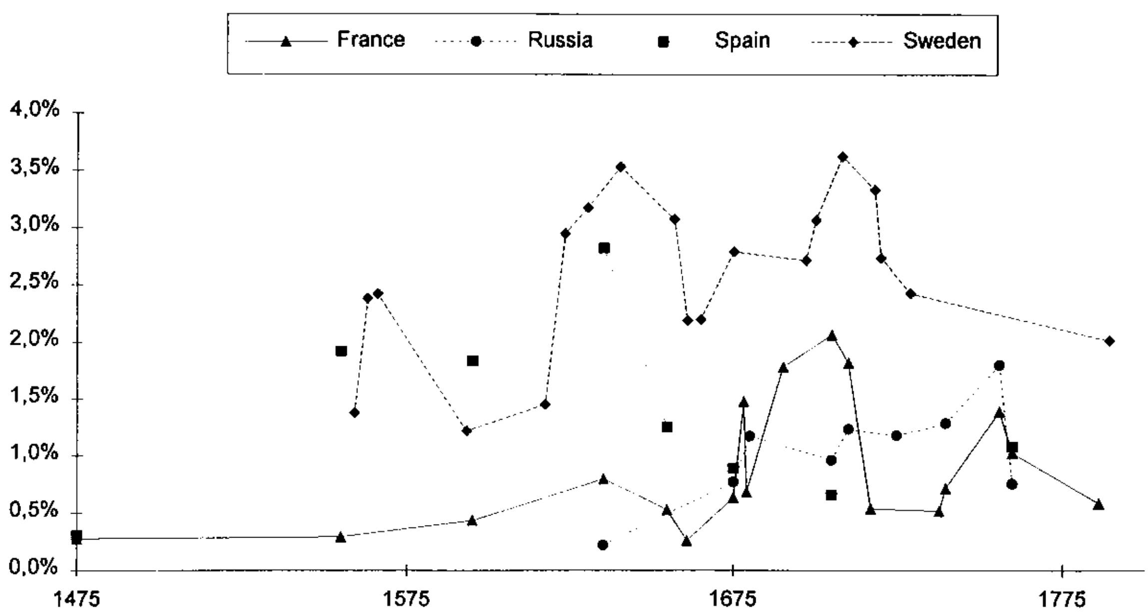


Fig. 3. Percentage of population in the armed forces approximately 1475–1789. Sources: Lindegren 1993.
Note: The figures for the Swedish forces include only native Swedes and Finns, and before 1623 the naval forces have been omitted for lack of evidence. For the other states the curves only show the proportion of the army and not the navy to the population, which means that they are not fully comparable with the Swedish figures. More important than this however, is that the non-Swedish figures also include foreign troops. The population figure is uncertain for the period before the mid eighteenth century. Also the figures become less certain the farther back in time one goes. At the end of the seventeenth century the proportion of the population in arms in Denmark (including Norway), had risen to the same level as that in Sweden. After 1720 the percent of the population in the military for Denmark was the highest in Europe.

With the creation of a huge army and the successful expansion of power, balance within the Swedish society underwent a dramatic shift. The army was the King's instrument of power with the kingship, by birthright assuming the position as commander in chief. At the end of his reign Gustav II Adolf had no problems dictating his will.

Between 1560 and 1620 the war politics led to an ever increasing taxation level. This increase at the same time led to an increase in the rent on noble land. It was a general tax increase otherwise differentiation in the rent level would have led to migrations of peasants between different types of land. The King's exploitation had not yet reached its maximum as this period witnessed a steady growth in population and new land clearing, which in turn led to even higher tax and rent returns.

In historical terms one might say that state and nobility during this period regained from the peasants what had been lost in the agrarian crises of the late Middle Ages due to the war-taxation. About 1620 the taxes were raised successfully for the last time. Subsequent efforts to raise the taxes, and they were frequent, all failed. What was gained in one way was lost in another. The exploitation level had reached its maximum. Slowly a new situation was evolving where nothing more could be had of the peasants and where raises in taxation instead could only lead to a redistribution of the societal surplus within the ranks of the ruling elite. A growing discontent with the new 'Military State' soon surfaced. It would take a hundred years to create a modernized version designed to defend the Baltic Empire, yet not to expand at the expense of its neighbours.

In the mean time half a million Swedish and Finnish men died in active war service. On average 30% of all men who reached the age of 15 died in the wars. Of the soldiers, 75%, died of diseases; 10% were killed in battles or mortally wounded, 5% died during sieges and 10% while being prisoners of war. Their fate was typical of the early modern soldiers. The battle-fields were not that dangerous and the risk of being killed in action for an ordinary man was rather insignificant. It was much more likely that an officer, who often was a nobleman, was killed than a common soldier.

If the fate of the soldiers was normal, the extent of the losses was not. In the period 1560–1659 Castile lost about 11% of its adult male population in the constant wars. This is widely recognised as something of a record. The losses for Sweden during this period were about the same as those in Castile, yet from 1620–1719, Sweden lost three times this number of men.

How then was it possible for the society to sustain losses of this magnitude for such a prolonged period? The reason why is closely connected with the structure of the prevailing agriculture. The crucial factor was whether or not women could take over the work of the men. Generally speaking this depended on how much arable land the peasants had to till and if the soils were light or not. In areas where the plots were small the women could manage very well, whereas in the big plains areas with heavy clay it was not possible. As a consequence, most soldiers in early modern Europe were recruited in the marginal agricultural areas, such as Sweden. Swedish women could manage reasonably well even with a terrible shortage of men. Further, the surplus production in these marginal areas was small, which meant that the economic impact due to the loss of male labour was very small for the lords. For the household economy of the peasants the situation was more serious.

To summarize, interior economic reasons, going back to the agrarian crises of the late Middle Ages were favourable to the establishment of a strong centralized state in Sweden. Such states were in general dependent on the existence of exterior wars or at least the constant threat of war. The same conditions were at hand in Western Europe, but not in Eastern or the rest of Northern Europe. Thus, Sweden was competing with states organized along medieval lines. Even if they all were larger and richer they could not utilize their resources for war purposes in a way that even resembled what the Swedish State was able to do at the same time. However, during the seventeenth century, Denmark, Russia and Brandenburg-Prussia reorganized along modern lines, largely a response to the Swedish onslaught. During the reign of Gustav II Adolf, Sweden took yet another step, the establishment of the very aggressive 'Military State'. Partly the development was due to the political skills of the King and his chief advisor, Axel Oxenstierna, but it was also based on fundamental structures in Swedish society. Sweden was made a part of the European economy thanks to a planned effort to make use-values into exchange-values of hard currency by way of the mining and metal sectors. This effort was facilitated by Dutch capital and a number of other favourable circumstances. The nature of Swedish agriculture was such that it could sustain very heavy and prolonged losses of men, supported by the work of women. Poor agricultural lands and the small, scattered population made major attacks on Sweden unwarranted. A war in Sweden could never 'feed itself' as one said at the time. From the Swedish point of view it was the other way around. Swedish troops could be deployed on the other side of the Baltic and at least theoretically live entirely on the expense of the enemy's territory. In 1630, when entering the Thirty Years War, Gustav II Adolf's goal was that the war should 'feed itself'. From a Swedish vantage point these is no doubt that it did so to a large extent. However, Sweden also had to pay a very high price. On the other hand the country gained recognition, cultural and material influence, provinces etc. In this paper we will deal with this problem by making a systems analysis of costs and benefits of the Thirty Years War for Sweden.

Overview of the Swedish Baltic Empire

SWEDEN'S TERRITORIES

The Swedish Baltic Empire (Fig. 4) can be summarized into three periods:

1561–1660 Aggression, expansion
1661–1708 Defense
1709–1720 Decline

Karelia, in Finland, and the Baltic states, Estonia and Latvia, which came under Swedish control at an early state were definitely lost in 1720. The North German territories, which Sweden got in the Westphalian peace in 1648 were also lost in 1720, except for Stralsund (Swedish until 1815). But the provinces in the southern and western part of the Scandinavian peninsula, as well as Gotland and the provinces of Jämtland and Härjedalen (Swedish in 1645 and 1658), have ever since remained Swedish. Thus, the Empire resulted in the integration into Sweden of the very fertile provinces in the south and also a liberation of the Swedish trade with western Europe as Denmark no longer could levy the Sound toll.

SWEDEN'S RESOURCE BASE

The 16th century Sweden is described by Heckscher (1941) as a "barbary in affluence". The agrarian production more than sufficed. Even under the pressure of the continuing warfare in the 17th century, Sweden, including the Baltic territories, was able to feed its population even if crop failures occasionally created shortages and hunger. Only about 20% of the 45 million ha of forest land were in use (Table 2) representing sizable reserves of wood resources.

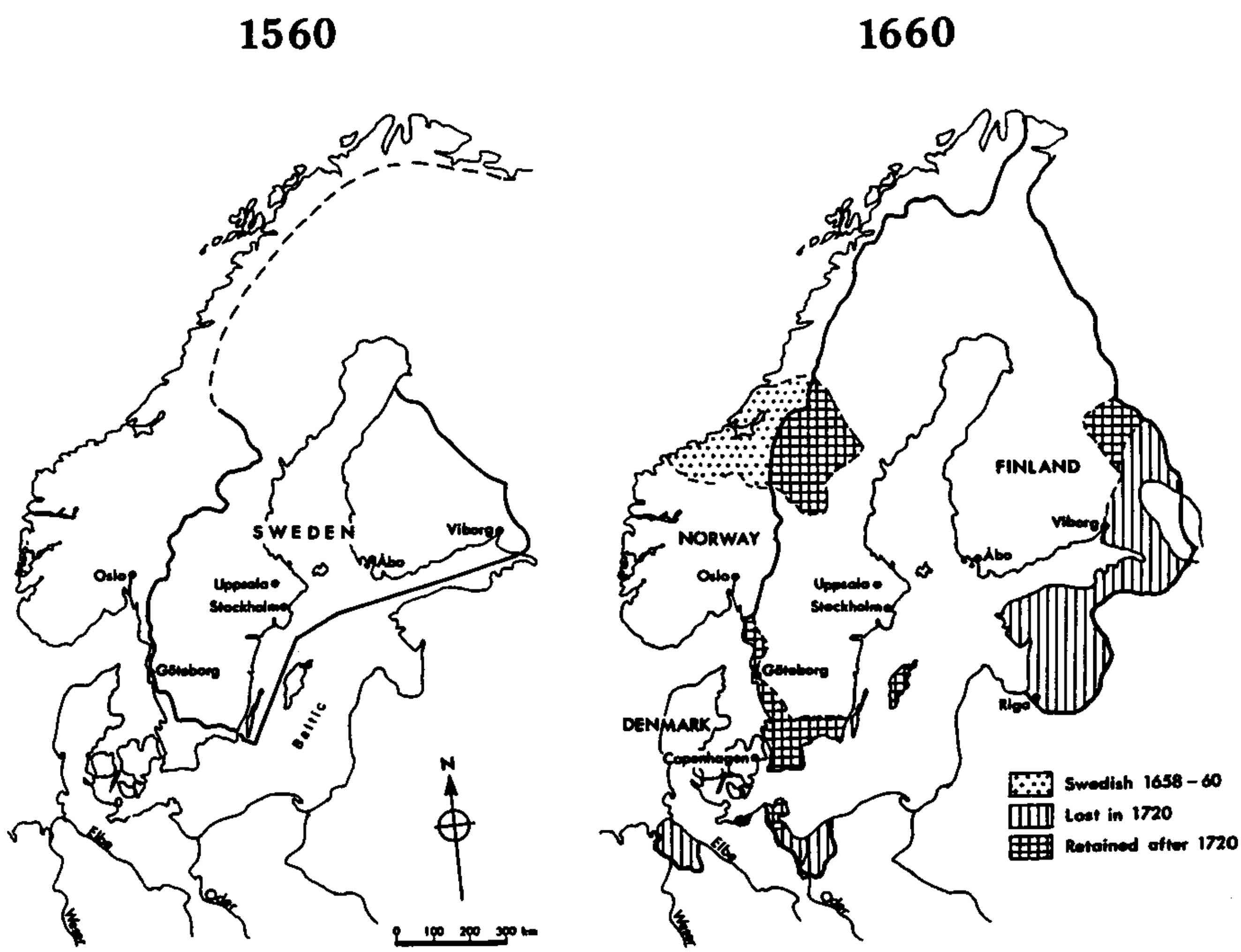


Fig. 4. Sweden in 1560 and the 'Baltic Empire' of 1660–1720.

Table 2. *The forest resource in Sweden, including Finland, in the mid-17th century*

	Area	Stock		Solar EMERGY (10^{20} sej)	Annual harvest (m^3 yr^{-1})
	(million ha)	(m^3/ha)	(m^3)		
Virgin forests	35.3	150	5.25 E9	1,970	
Forest in use	9	80	0.72 E9	270	12.6 E6
Total	44		5.97 E9		

Ref. Appendix 2.

Table 3. *Inputs per tonne for the production of steel, copper, silver and tar*

Item	Steel	Copper	Silver	Tar
Wood, m3/t	75 (1)	288 (3.8)	9,064 (121)	38 (0.50)
Labour, MD/t	238 (1)	550 (2.3)	36,000 (151)	73 (0.30)
Animal, AD/t	140 (1)	196 (1.4)	8,000 (57)	15 (0.10)

Figures in brackets = Ratios relative to steel = 1; MD = man-days, AD = animal-days.

Of utmost importance for the war economy was the production of goods for export through which funds to finance the war were obtained. For various reasons due to drastically shrinking production in other countries and regions, Sweden achieved practically world monopoly on her three most important industrial products — copper, steel and tar — for which large quantities of wood was essential. Of the annual harvest of wood from the forest, 12.6 million m^3, 2.71 million m^3 or close to 22% was used for production of these export goods. In Table 3 the inputs into this production is summarized. It is estimated that about 7.5 million mandays were required in these industries.

PRODUCTION OF SWEDEN'S EXPORT PRODUCTS

The export products financing Sweden's interventions on the North European war theatre were steel, cop-

Table 4. *Annual production and export of silver, copper, steel and tar in the mid-17th century. Tonne per year*

	Production	Export
Silver	1	–
Copper	2,070	1,800
Steel	20,000	18,000
Tar	16,000	14,500

Ref. Appendices 3, 4 and 5.

Table 5. *The relative values of the export of tar, steel and copper per unit weight and per unit wood used up in the production*

	% share of export value	Price ratio per unit weight	Export value per unit wood
Tar, pitch	7.3	1	1
Iron, steel	47.8	5.3	2.6
Copper, brass	32.3	36	44
Total	87.4		

Source: Heckscher (1936), Bd 1.1, Bil. V, for export values 1642, 1645 and 1649.

per and tar. Most of the annually processed metals and tar were allocated for the export market (Table 4). The export of these three products was close to 90% of Sweden's export in the mid-17th century. In the Table 5, a comparison is presented of the relative values per unit weight and of the ratio of export value per unit volume of wood used up for the production of these commodities. The table shows that a unit of wood yielded for steel about 3 and for copper about 40 times more export value than tar. This can be seen as a biophysical support for the economic policies of that time, giving highest priority for copper production and lowest for tar. But tar production was entirely based on renewable resources whereas steel and copper involved an exploitation of ores, a finite resource.

Emergy Analysis

NATIONAL EMERGY BASIS

Figure 5 illustrates the system of Sweden in overview. Shown are primary energies driving forest and agricultural production which forms the basis for industries of charcoal and steel making. Trade with Middle Europe is controlled through military actions issued by the king. The area of Sweden-Finland in the mid-17th century was about 20% occupied. Whereas the EMERGY of the whole area was potentially available, this analysis considers only the contributions of the occupied areas to the economy. Area that was populated utilizing farms and forests was then 20% of 660,000 km^2 (1.32 E7 ha), the Sweden-Finland of that period. Within the occupied area only 20% was cultivated in crops or managed pasture, but the surrounding lands were supplying products from the combined work of forest production, wildlife habitat, water processing and mineral storage. Figure 5 shows the major components of Sweden during this period, including basic production, class divisions, State control and the overseas army. The circulation of Riksdalers between peasants and town was estimated to be small (200,000 Rdr) and thus money is not shown to circulate amongst the lower class and is never paid to the environment for its work.

Annual SOLAR EMERGY-use for Sweden during this period is shown in Table 6. A total input of 55 E20 sej were used in the combined ecologic-economic system. Renewable sources from the environment made up an estimated 87% of Sweden's total support base. This is shown as transpired rain driving forest production (Table 6, item 1). Because of the way the solar transformity of forest production was calculated from global totals, the EMERGY of forests includes the coupled and contributing energy inputs of direct sunlight and winds. EMERGY-use per person is a kind of standard of living index. Mid-17th century Sweden had 4 E15 sej/person-yr (Table 6, note 7). This is comparable to today's world average (Odum 1992), suggesting that Sweden had a generally high quality of life during its Baltic Empire period. Present Swedish EMERGY/capita is 28 E15 sej/p-yr (Doherty et al. 1992), seven times higher than 350 years ago — a measure of increased wealth for Sweden. The difference is today's greater reliance on outside resources and the percent of EMERGY-use that is renewable. As might be expected for an agrarian nation just emerging from isolation, Sweden's self-sufficiency is high; 94% of its EMERGY-base is from indigenous sources (6% imported) and 87% is renewable. This is contrasted with present day Sweden where 65% of its EMERGY is imported and 25% renewable (Doherty et al. 1994).

Sweden's reserve of forests represents a large available EMERGY base. Almost 2000 E20 sej was stored in biomass of as yet untouched, virgin forests (Table

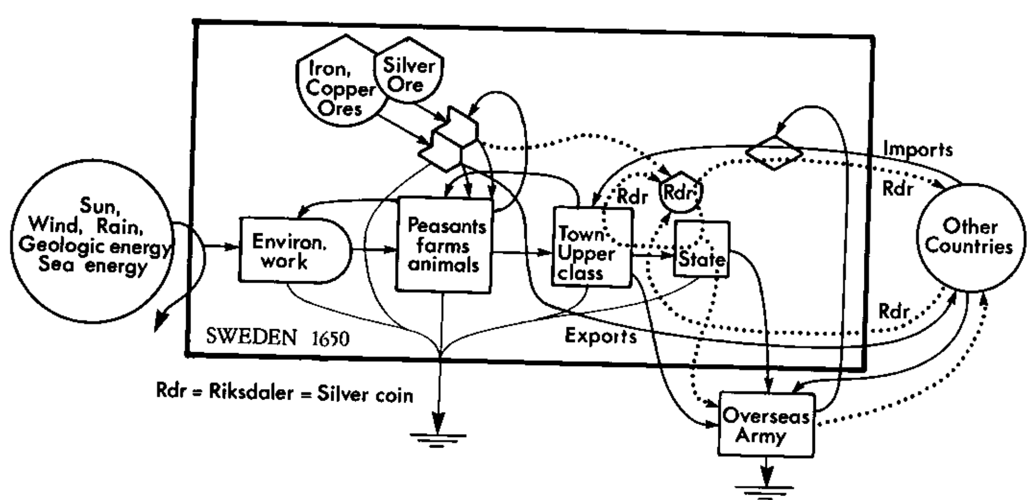


Fig. 5. Overview system of mid-17th century Sweden with its basic production, class divisions, control by the State through the circulation of currency and its overseas army, and its exchange with other European States. Riksdalers, shown as dotted lines moving in opposite direction of resources, was largely circulated among the elite, the State and foreign markets. See Appendix 7, Symbols of the Energy Language.

Table 6. *Annual SOLAR EMERGY production and use in Sweden, mid-17th century*

Footnote	Item	SOLAR EMPOWER (10^{20} sej/yr)
1	Forest production	48.05
2	Stream, hydropotential	3.10
3	Mineral and metal ores	0.71
4	Imported goods & services	3.24
5	Total EMERGY used	55.10

Area that was populated utilizing farms and forests was considered 20% of 660,000 km^2; the Sweden-Finland area of the Baltic Empire in mid-17th century: (6.6 E11 m^2) (20%) (ha/10000 m^2) = 1.32 E7 ha;

1 Forest emergy calculated as forest production, based on evapotranspiration (50% of snow, rainfall):
(0.4 m/yr ET) (1 E4 m^2/ha) (1 E6 g/m^3 H_2O density) (5 J/g Gibbs energy) (1.82 E4 sej/J) = 3.64 E14 sej/ha/yr;
(3.64 E14 sej/ha/yr) (1.32 E7 ha) = 4.8 E21 sej/yr.

2 Stream potential emergy = (0.4 m runoff) (1.32E11 m^2) (30 m, mean elevation for occupied lands) (1000 kg/m^3 H_2O) (9.8 m/s^2) = 1.55 E16 J/yr; (1.55 E16 J/yr) (20000 sej/J) = 3.1 E 20 sej/yr.

3 Mineral ores mined and processed:
Iron ore: (44.4 E9 g/yr) (1 E9 sej/g) = 0.44 E20 sej/yr
Copper ore: (5.18 E9 g/yr) (5 E9 sej/g) = 0.26 E20 sej/yr
Silver ore: (1 E8 g/yr) (5 E9 sej/g) = 0.005 E20 sej/yr
total EMERGY of extracted minerals = 0.71 E20 sej/yr.

4 Imported goods and services: 2.7 E6 Rdr paid for imports (Lindegren 1993); solar emergy/Rdr for skilled labourers in Denmark estimated as 1.24 E14 sej/Rdr (Table 7): (2.7 E6 Rdr/yr) (1.2 E14 sej/Rdr) = 3.24 E20 sej/yr.

5 Sum of items 1, 2, 3 and 4. Marine inputs not included as their use was small.

6 Empower density = Annual emergy-use (item 4) divided by area of Sweden's Baltic Empire:
(55 E20 sej/yr) / (1.32 E7 ha) = 415 E12 sej/ha/yr

7 Emergy-use per capita = (55 E20 sej/yr) / (1.4 E6 persons) = 3.95 E15 sej/p-yr.

2) — 40 times the total amount of EMERGY used annually. The annual harvest of 14 million sej/yr represents only 5% of the forest reserves that were actually in use at the time. It is clear from this analysis and the subsector analyses which follow, the important role of forests in Sweden's struggle for power.

CURRENCY AND TRADE

In the lower part of the hierarchy of 17th century Sweden, peasants and markets were generally organized through a system of barter, although commodities were given a Riksdaler value. Silver and copper coins were circulated that had designated Rdr-value, but most of the silver was withdrawn from home circulation to be used in foreign exchange along with new coins manufactured each year from mined silver.

At the higher level of the state and upper classes there was a larger circulation of Riksdalers, more often in silver or silver-backed paper. Assigning the national EMERGY budget to this circulation of currency is not appropriate since the currency was only within the upper class and exchanged between trading states. This would result in an overestimate of the buying power of the Riksdaler. Estimates of buying power are given as EMERGY/currency indices (Table 7).

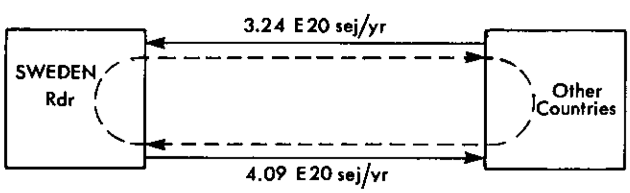
For example, Fig. 6 shows the EMERGY exchange ratio for Sweden's exports in exchange for Riksdalers that were then paid out for goods and services from abroad. More EMERGY (1.25 times more) was sent out in trade than was obtained in return. This inequitable exchange suggests that Sweden's trade actions benefited its trading partners, subsidized from its large EMERGY base at home. Of course, there was a great deal of smuggling by soldiers returning home with commodities taken from occupied territories during this period. No estimate was made of this contribution, as there is no known quantifications of these activities. It is surmised that this would represent a net contribution to our estimates of imports, perhaps making the exchange more balanced between Sweden and Middle Europe.

If we consider the EMERGY backing today's currency (SEK) with the EMERGY/Riksdaler of 1650,

Table 7. *Prices and EMERGY/Riksdaler ratios for resources in mid-17th century Sweden (Rdr = 1 Riksdaler)*

Note	Item	Unit	Rdr price	SOLAR EMERGY	sej/Rdr (10^{12})
1	Copper	t	460	51 E15	112
2	Bar iron	t	50	12 E15	232
3	Silver, Riksdaler	g	1/24	1.4 E12	34
4	Unskilled labour, Sweden	yr	60	4.0 E15	67
5	Skilled labour, Sweden	yr	150	56 E15	373
6	Unskilled labour, Denmark	yr	60	3.0 E15	48
7	Skilled labour, Denmark	yr	150	18 E15	120

1 Copper analysis, Table 10.
2 Iron analysis, Table 11.
3 Silver analysis, Table 12; 1 Rdr = 24 g silver.
4 Swedish unskilled worker: (55 E20 sej/yr; Table 6) / (1.4 E6 people) = 4.0 E15 sej/person/yr.
5 Swedish skilled labourer considered those in town (7% of population): (4.0 E15 sej/p-yr)/(0.07) = 5.6E16 sej/p-yr.
6 Danish unskilled services: (4.3 E6 ha) (4 E14 sej/ha/yr) / (6 E5 people) = 2.9 E15 sej/p-yr.
7 Danish skilled services considered those in town (16% of population): (2.9 E15 sej/p-yr)/(0.16) = 1.8 E16 sej/p-yr.



EMERGY exchange ratio = Imports/Exports
= (3.24 E20 sej)/(4.49 E20 sej)
= 0.80

Fig. 6. EMERGY evaluation of foreign trade with mid-17th century Sweden.
Export products include:
Copper: (1.8 E9 g/yr) (51 E9 sej/g) = 9.24 E19 sej/yr
Bar iron: (1.8 E10 g/yr) (10.2 E9 sej/g) = 1.84 E20 sej/yr
Silver coins: (53,000 Rdr/yr) (24 g Ag/Rdr)
(1.42 E12 sej/g) = 1.81 E18 sej/yr
Tar: (1.45 E10 g/yr) (2.3 E9 sej/g) = 3.34 E19 sej/yr
Riksdalers value of other exports not accounted for (total export revenues less revenues from metals and tar):
(0.26 E6 Rdr/yr) (373 E12 sej/Rdr for skilled labour) = 9.7 E19 sej/yr
total exported emergy = 4.09 E20 sej/yr
Imports evaluated using index of EMERGY/Rdr for foreign countries:
(2.7 E6 Rdr/yr) (120 E12 sej/Rdr) = 3.24 E20 sej/yr

we get a perspective on the relative buying power of Sweden's currency over time:

(373 E12 sej/Rdr) / (0.23 E12 sej/SEK)

= 1620 SEK1988/Rdr1650

or 6.5 SEK/US \$, 1988 exchange = 250 \$/Rdr

This suggests that in the mid-17th century, a Riksdaler represented 1600 times more real wealth than today's Swedish krona, SEK. This can be considered a measure of inflation.

MILITARY OPERATIONS

When the support of the military is included as overseas export an even greater loss for Sweden is realized. Through armaments, ships and soldiers sent abroad for war, 3.6 E20 sej/yr were drawn from Sweden (Table 8) — almost doubling the export of resources from home. 88% of this flow was the EMERGY value of the average annual loss of soldiers (= annual recruitment). However, the overseas army drew resources from the host countries which went in support of its missions which include land resources, feedback of information, culture and the basis for later trade and industrial competition.

Occupied territories that have remained under Swedish rule ever since include 26,000 km^2 of Southern Provinces including Gotland and the 34,160 km^2 of Jämtland (see Appendix 6). These lands contributed almost 19 E20 sej/yr to Sweden — increasing its EMPOWER (EMERGY flow per year) by 34%. In addition, an estimate was made of the EMERGY supporting military officers, businessmen and artisans that immigrated into Sweden as a result of the wars, about 140 persons per year. Using the EMERGY-

Table 8. *EMERGY evaluation of annual Swedish overseas military operations in the mid-17th century.*

Footnote	Item	Annual Inputs	SOLAR TRANSFORMITY (sej/unit)	SOLAR EMERGY (10^{15} sej/yr)
1	Riksdalers	15,000 Rdr	34 E12	510
2	Bronze cannons	20 tonnes	51 E15	1,020
3	Iron cannons, horse shoes	20 tonnes	10.2 E15	204
4	Horses sent	1100 ind.	1.5 E1	51,606
5	Ships	2.7 ships	13.3 E18	35,910
6	Armaments for navy	50 tonnes	6.3 E16	3,150
7	Soldiers	4000	ind. 8.0 E16	320,000
8	Total support from Sweden			362,400
From allied states and occupied lands for Swedish troops:				
9	Monetary aid from France	15,000 Rdr	34 E12	510
10	Horses	9550 ind.	7.2 E14	6,880
11	Soldiers	12,400 ind.	3.0 E15	37,200
12	Supplies sent	1.5 E6 Rdr	124 E12	186,000
13 Total from occupied area				230,590

1 15,000 Rdr/yr sent to armies; ST of 24 g silver coin = 34 E12 sej/Rdr; Table 7, item 3.
2 20t Cu sent for bronze cannons; ST for copper = 51 E9 sej/g; Table 10.
3 20t bar iron sent for iron cannons, horse shoes, etc.; ST for iron = 10.2 E9 sej/g; Table 11.
4 1100 horses sent abroad, ST considered production in support of 2 year old horse: (2 ha/horse) (2 yr) (3.64 E14 sej/ha/yr production; Table 6, item 1) = 1.46 E15 sej/horse. 52.7 ships sent out per year; EMERGY estimated as sum of wood and labours:
5 a) Wood = (30,000 tonne ship) (3.2 E14 sej/t ship timber; Table 1, item 8) = 9.6 E18 sej/ship
b) Services in ship building = (1.0 E4 Rdr/ship) (373 E12 sej/Rdr, skilled labour; Table 7, item 5) = 3.73 E18 sej/ship
ST for ships = a + b = 13.3 E18 sej/ship
6 Armaments = annual need of metal for period 1640–1650 was an estimated 25 tonnes bronze and 25 tonnes iron: (50t armaments/yr) (6.3 E16 sej/tonne; Table 1, item 15) = 3.15 E18 sej/yr
7 4000 soldiers sent abroad per year; considered emergy-used per capita multiplied by mean age of soldiers: (20 yr old mean age) (4.0 E15 sej/p-yr) = 8.0 E16 sej/soldier
8 Total annual EMERGY support from Sweden = sum of 1–7.
9 Money from France: 5% of 300,000 Rdr = 15,000 Rdr/yr.
10 Horses: (3.6 E14 sej/ha/yr; Table 6, item 1) (2 ha/horse) = 7.2 E14 sej/horse/yr; 125 horses used in company of 162 men = 0.77 horse/man; (12,400 men) (0.77 horses/man) = 9550 horses/yr
11 12,400 soldiers/yr supplied from allies evaluated using emergy supporting general labour in Denmark (Table 7, item 6): (1.24 E4 soldiers/yr) (3 E15 sej/p-yr) = 3.72 E19 sej/yr
12 Price of commodities supplied from allies = 31.5 E6 Rdr/yr; considered emergy/Rdr for labour in Denmark.

use/capita ratios for highly skilled labour (see Table 7 and Appendix 6), an estimated contribution of 0.3 E20 sej/yr resulted from the immigration. This represents a 10% addition to the EMERGY of annual imports (Fig. 6). It is believed that the smuggling into the country was considerably higher than the outgoing. The officers and returning soldiers also brought back objects of art and other valuables, which they had acquired or looted. These inflows are not evaluated here. However, the pay offs from the war should presumably have shown up as increased imports of general goods and services, which our analysis does not indicate.

Not evaluated here was the even larger Swedish controlled army of mercenaries and allies numbering up to 100,000 troops that were also supported by the occupied lands. Starting with high transformity military resources of ships and their armaments, it was possible to cascade control through a small cadre of Swedish troops to control the larger army and hence the lands surrounding the Baltic Sea.

The EMERGY analysis of military engagements support Lindegren's postulate (1993) that the military regime drew heavily on its own resources to support its war effort, with disproportionately less being returned to Sweden for its investment. It is reasonable

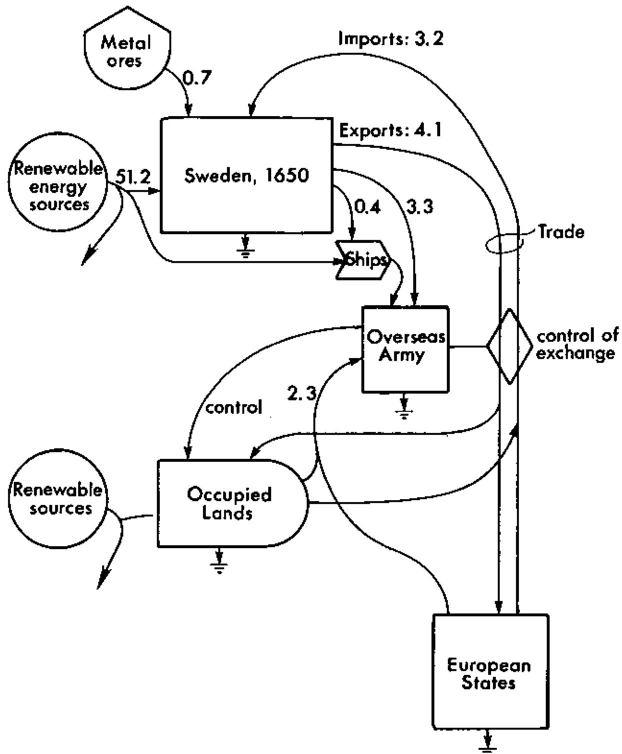


Fig. 7. Summary EMERGY diagram of mid-17th centrury Sweden, its overseas army and trade with other countries. Values on pathways are 10^{20} solar emjoules per year. Derivations are given in Tables 6, 7, and 8.

to surmise that Sweden's development of technology and financial markets were expedited through the stimulus of the war. It remains a question, however, whether the gains incurred by Sweden and its people outweigh the losses. Our analysis suggests perhap that Sweden did not receive a net surplus of value, measured by EMERGY expenditures and gains, due to the war.

The use of a military umbrella to control a trade perimeter is not unlike that maintained up to the Iron Curtain by Western nations through much of the 20th century. A similar study of the EMERGY basis for U.S. defense investment reported a net EMERGY benefit gained by the United States by facilitating a secure environment for foreign markets and exchange (Odum 1992, using data from Dalton 1986). It is possible that Sweden's overseas military operated similarly, and in fact one generally agreed upon result of the war was the opening of the Baltic straights to trade.

METALS AND TAR PRODUCTION

In order to more accurately address trade and military operations, EMERGY analyses were made of Sweden's major industrial sectors in the mid-17th century. These include tar and pitch, copper, iron, and silver (Tables 9–12). These analyses are important to our study since solar transformities were calculated for these export products which were used in subsequent analyses of trade and warfare. We present them here for general reference. EMERGY inputs are summarized in Table 13. The role of wood is again confirmed as wood and charcoal inputs together constituted a major EMERGY inputs to these industries, generally followed by the EMERGY sup-

Table 9. *Tar and pitch production in Sweden in the mid-17th century for an annual production of 16,000 tonnes*

Note	Item	Direct energy (J/yr, g/yr)	Solar transformity (sej/J, sej/g)	SOLAR EMERGY (10^{15} sej/yr)
1	Wood	5.03 E15 J	4,000	20,120
2	Horse, ox power	4.18 E12 J	1.0 E5	418
3	Human labour	3.35 E12 J	4.75 E6	15,913
4	Total used			36,451
5	Tar and pitch	1.6 E10 g/yr		
6	EMERGY/gram	(3.65 E19 sej/yr) / (1.6 E10 g/yr) = 2.28 E9 sej/g		

See Appendix 3 for explanation of data.
1 Fuel wood, heat value = (600,000 m^3/yr) (2.33 MWh/m^3) (3.6E9 J/MWh) = 5.03E15 J/yr.
2 Animal power: 2 animal-days/barrel tar; (2 AD/bbl) (125 l/bbl) (1.1 kg/l; specific wgt of tar) (1000 kg/t) = 14.5 AD/t; (14.5 AD/t) (0.5 kW/AD) (10 hr/d) (3.6E6 J/kWh) (16,000 bbl/yr) = 4.18E12 J/yr.
3 Human work: 10 man-days/barrel tar; (10 MD/bbl) (125 l/bbl) (1.1 kg/l) (1000 kg/t) = 72.7 MD/t; (72.7 MD/t) (0.08 kW/MD) (10 hr/d) (3.6E6 J/kWh) (16,000 t/yr) = 3.35E12 J/yr.
4 Sum of inputs (items 1–3).
5 Average production of tar and pitch in Sweden from 1640–1650.
6 Solar transformity for tar and pitch production in mid-17th century Sweden = total EMERGY used (item 4) / grams tar produced (item 5).

Table 10. *Copper production (pure) in Sweden in the mid-17th century for an annual production of 2070 tonnes*

Note	Item	Direct energy (J/yr, g/yr)	Solar transformity (sej/J, sej/g)	SOLAR EMERGY (10^{15} sej/yr)
1	Wood	9.36 E14 J	4,000	3,740
2	Charcoal	1.80 E15 J	18000	32,426
3	Hydropower	1.51 E13 J	20,000	302
4	Horse, ox power	7.56 E12 J	1.0 E5	756
5	Human labour	3.64 E12 J	4.75 E6	17,290
6	Copper ore used	5.175 E10 g	1 E9	51,750
7	Total used			106,264
8	Copper produced	2070 E6 g/yr		
9	EMERGY/gram	(1.06 E20 sej/yr) / (2.07 E9 g/yr) = 5.13 E10 sej/g		

Data from Sundberg (1991, 1992) with updates explained in Appendix 4.
1 Fuel wood, heat value = (260 GWh/yr) (3.6 E12 J/GWh) = 9.36 E14 J/yr
2 Charcoal, heat value = (1,112 GWh/yr wood equivalent) (0.45 charcoal energy/wood energy) (3.6 E12 J/GWh) = 1.80 E15 J/yr.
3 Hydro-power = (4.2 GWh/yr) (3.6 E12 J/GWh) = 1.51 E13 J/yr.
4 Animal power = (2.1 GWh/yr) (3.6 E12 J/GWh) = 7.56 E12 J/yr.
5 Human work = (1.01 GWh/yr) (3.6 E12 J/GWh) = 3.64 E12 J/yr.
6 Copper ore = 51,570 tonnes produced 2070 t pure Cu (4% of ore).
7 Sum of inputs (items 1–6).
8 Average copper production in Sweden from 1640–1650.
9 Solar transformity for copper production in mid-17th century Sweden = total EMERGY used (item 7) / grams copper produced (item 8).

Table 11. *Bar iron production in Sweden in the mid-17th century for an annual production of 20,000 tonnes*

Note	Item	Direct energy (J/yr, g/yr)	Solar transformity (sej/J, sej/g)	SOLAR EMERGY (10^{15} sej/yr)
1	Wood	2.52 E15 J	4,000	10,080
2	Charcoal	4.54 E15 J	18000	81,648
3	Hydropower	1.51 E14 J	20,000	3020
4	Horse, ox power	5.04 E13 J	1.0 E5	504
5	Human labour	1.37 E13 J	4.75 E6	65,075
6	Iron ore used	44.4 E10 g	1 E9	44,444
7	Total used			204,771
8	Bar iron produced	20,000 E6 g/yr		
9	EMERGY/gram	(2.05 E20 sej/yr) / (2.0 E10 g/yr) = 1.02 E10 sej/g		

Data from Sundberg (1992).
1 Fuel wood, heat value = (700 GWh/yr) (3.6 E12 J/GWh) = 2.52 E15 J/yr
2 Charcoal, heat value = (2,800 GWh/yr wood equivalent) (0.45 charcoal/wood) (3.6 E12 J/GWh) = 4.45 E16 J/yr
3 Hydro-power = (42 GWh/yr) (3.6 E12 J/GWh) = 1.51 E14 J/yr.
4 Animal power = (14 GWh/yr) (3.6 E12 J/GWh) = 5.04 E13 J/yr.
5 Human work = (3.8 GWh/yr) (3.6 E12 J/GWh) = 1.37 E13 J/yr.
6 Iron ore = (2.0 E10 g bar iron) / (0.45) = 4.44 E10 g iron ore (45% of ore).
7 Sum of inputs (items 1–6).
8 Average bar iron production in mid-17th century Sweden (Heckcher 1936, p. 468).
9 Solar transformity for bar iron production in mid-17th century Sweden = total emergy used (item 7) / grams bar iron produced (item 8).

Table 12. *Silver production in Sweden in the mid-17th century for an annual production of 1 tonne*

Note	Item	Direct energy (J/yr, g/yr)	Solar transformity (sej/J, sej/g)	SOLAR EMERGY (10^{15} sej/yr)
1	Wood	6.6 E13 J	4,000	260
2	Charcoal	8.2 E12 J	18,000	150
3	Hydropower	1.29 E11 J	20,000	3
4	Horse, ox power	1.4 E11 J	1.0 E5	14
5	Human labour	1.04 E11 J	4.75 E6	494
6	Silver ore used	1.0 E8 g	5 E9	500
7	Total used			1421
8	Silver produced	1.0 E6 g/yr		
9	EMERGY/gram	(1.42 E18 sej/yr) / (1.0 E6 g/yr) = 1.42 E12 sej/g		

Analysis based on production at the Sala mine in mid-16th century and extrapolated for country-wide production of 1 tonne. Data from Engelbertsson (1987), Granström (1940) and Norberg (1978). See also Appendix 5.
1 Fuel wood = (7.0 m^3/kg Ag) (1000 kg/tonne) (4.7 E5 g/m^3) (2 E4 J/g) = 6.6 E13 J/t
2 Charcoal = (2.1 m^3/kg Ag) (1000 kg/t) (1.3 E5 g/m^3) (3 E4 J/g) = 8.2 E12 J/t.
3 Hydro-power = (0.036 GWh/yr) / (1 t Ag/yr) (3.6 E12 J/GWh) = 1.29 E11J/t.
4 Animal power = (0.04 GWh/yr) / (1 t Ag/yr) (3.6 E12 J/GWh) = 1.44 E11J/t.
5 Human = (0.029 GWh/yr) (3.6 E12 J/GWh) = 1.04 E11J/t.
6 Silver ore = 1E8 g ore produced 1 t pure Ag (1% of ore).
7 Sum of inputs (items 1–6).
8 Average silver production in mid-17th century Sweden = 1 tonne/yr.
9 Solar transformity for silver production in mid-17th century Sweden = total EMERGY used (item 7) / grams silver produced (item 8)

Table 13. *Summary of SOLAR EMERGY contributions from the three most important export products — tar, steel and copper — and for silver in Sweden, 1640–1650. Inputs are given as a percent of total EMERGY*

	SOLAR EMERGY sej/yr	SOLAR TRANSFORMITY sej/g	SOLAR EMERGY in percent				
			Wood	Charcoal	Human	Other[1]	Ore
Tar, pitch	37 E18	2.3 E9	55	—	44	1	—
Steel	205 E18	10.7 E9	5	40	32	2	22
Copper	106 E18	51.3 E9	4	30	16	1	49
Silver	1.4 E18	1.4 E12	18	11	35	1	35

1 Other inputs = hydro- and animalpower, were less than 2% of production inputs.

porting human labour. The geologic work of earth in production and placement of the basic ores for copper, steel and silver is from about 20 to 50 percent of the total EMERGY of these metals production. This is a storage of potential contribution that is still being mined today in Sweden. Although the solar transformity for silver was as much as 1000 times higher than copper or bar iron, its total EMERGY contribution to Sweden was small. Its role as a currency of exchange representing high quality services, however, is very high as seen in the Rdk-value of labour in Sweden (Table 7).

Summary and Conclusions

GENERAL

In this study we made a systems analysis of Swedish history. It attempts to evaluate the resource base of Swedish power in the mid-17th century using EMERGY as a numeraire. EMERGY is a measure of total resource contribution to combined ecological-economic systems. It evaluates both natural resources outside the economy as well as sources with market value on a common and equivalent basis. We will first present some general conclusions on which all authors agree followed by authors' remarks in which the study is viewed from their special perspectives.

The study is based on data from a 10-year period of the Baltic Empire in the mid-17th century although for some items averages from considerably longer periods are used. To give a complete overview of the Empire would have required the summing up of all flows from its inception to its collapse in 1720 and perhaps also impacts on the Swedish economy after that date.

Our analysis shows that Sweden during this period was an economy based largely on renewable resources. Forest contribution to the metal industry, agriculture and family formed the basis for the national wealth. The analysis also shows that the warfare did not pay off; the outflow of resources was about 25% greater than the inflow. If the inputs to the war machine are included, almost 2.4 times more EMERGY was sent out than delivered in return. It is notable that the loss of soldiers amounted to about 90% of the EMERGY cost of the war machine (Table 8). Furthermore the wars created misery for the larger part of the population and for practically all people on the war scene. However, if we include also the benefits of the culture, technology, the territorial gains and the liberation of trade remaining after the collapse of the Empire in 1720, one could possibly suggest a balanced account.

It is generally accepted by historians that the war policy, necessitating a maximal production in the metal industry, accelerated its growth and technology more than what was likely under peaceful conditions. One could claim that Sweden benefitted from this growth well beyond the next century. On the other hand, it is highly relevant to ask the question whether most of the progress and growth ascribed to the wars could not have been achieved without the aggression and warfare of 17th century Sweden. The answer to this question is presently largely speculative.

Sweden's entry into the Thirty Years War occurred only about 12 years after its beginning in 1618. It was in fact a war between Catholic and Lutheran States, and religious motives had a strong impact on Swedish policy decisions — a support to European brethren in their struggle against the Catholic emperor. It is probable that without the intervention of Sweden, the Catholic States would have conquered the Lutheran States in Germany and then continued to deal with the Nordic ones.

This aspect was strongly exploited by the King Gustaf II Adolf to persuade his council, his parliament and people to enter into the war. But the religious element was later on subdued and it is fair to say that then the Swedish policy was more imperialistic than idealistic. Thus, it remains an open question if Sweden really gained by its Baltic Empire. Attempts by historians to make up an economical balance sheet for this epoch have not produced any conclusive results and consensus. One possible interpretation of this is that the Baltic Empire breaks even, a conclusion which conforms with the results of our analysis and does not contradict its predictive power.

The hypothesis that economic and military power follow from the rate of production and use of resources is supported by this study. We hope and are also rather convinced that the presented analysis provides a holistic, consistent and also rather true account and that it may contribute in future studies of this period of Swedish and European history. Further, if a biophysical study proves to be relevant and valid, most likely it will also be a most useful tool for policy-makers of today.

COMPARISON OF ENERGY AND EMERGY ANALYSES

This study allows a comparison of two types of resource analyses:

(i) the selected energy analysis with a rather narrow system boundary, quantifying the inputs of direct energy: for wood the energy value of the wood, standing on the stump and for humans, animals and hydropower the direct power at the workplace. (See Appendices 3, 4 and 5.)

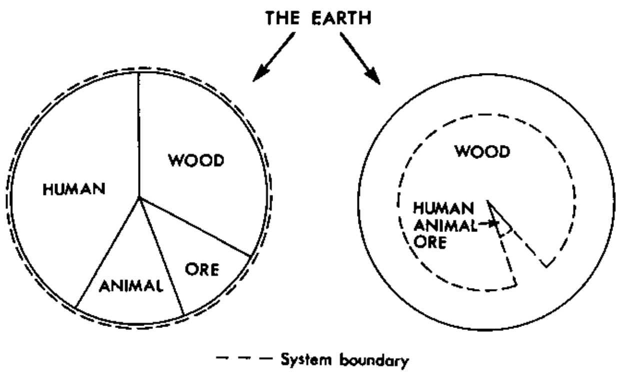


Fig. 8. Graph comparing the EMERGY analysis with the energy analyses presented in the Appendices 3, 4 and 5. The system boundary for the energy analyses is indicated with the dotted circle with a narrow boundary for humans, animals and ores. Boundary deliniations consider not only spatial contect, but also positional hierarchy of resources used up through production transformations, infering an account of total resource requirements.

(ii) the EMERGY analysis, accounting for indirect inputs to production, thus expanding the system boundaries and accounting for differences in quality of available energy used.

The result of the selected energy analysis shows that the power delivered by humans, animals and hydropower is not even 1% of the energy (heat value) of the wood, which accounts for more than 99% of the total energy input. The reason is that the indirect energies used up by humans, animals and for water is not included as they are outside the system boundaries as shown in Fig. 8.

In the EMERGY analysis all solar energy needed for growing wood and all the solar energy used up by nature and the human system to provide the power delivered by humans, animals and water is included. Solar transformities are used to estimate all direct and indirect energy — of one type — required. Transformity represents quality of the flows.

Table 13 reveals that tar production was very labour intensive and that the solar EMERGY of wood for the export products was about 34–55% of the total inputs. For the production of metals the ores were a large portion of the EMERGY input and this share is the energy used in the geological processes creating them. That EMERGY is in principal fossil, or stored, energy whereas the other inputs are renewables.

The two types of energy analysis answer different questions. The EMERGY analysis views the human household in a long resource perspective and lends itself to insights into human's use of finite resources and to environmental issues. The selected energy analysis is the correct first step in EMERGY evaluation. But it involves great risks as it omits the larger environmental energies.

Authors' Remarks — what does this study tell

THE SYSTEM ECOLOGISTS — HOWARD T. ODUM and STEVEN DOHERTY

Whereas the role of fuel scarcity in the causality of war is well established, as in the Second World War in Europe and Japan, the use of energy as an overall causal factor in history has mostly been qualitative. Many have been tempted to measure the many factors of historic causality using energy. But energies of different forms are not equal contributors to work, and little has come from efforts to use energy for all kinds of factors. In this study, however, after estimating the energy use involved in various aspects of historical process, each energy flow was multiplied by the EMERGY per unit to evaluate the magnitudes on a common solar EMERGY basis (the solar energy that would be required directly or indirectly to make the service or product). The theory is that products or services that require more can do more. Things that do not have effects proportional to what was required in their making tend to be discontinued. This leaves only those flows that do have effects commensurate with what was required to make them. In other words it is proposed that EMERGY measures historical causality.

Empower is defined as the EMERGY flow per unit time. A general system hypothesis is that self organization develops designs, efficiencies, hierarchies, and spatial patterns that maximize empower, because a system with more contributing resources can prevail over alternative designs. This is an updated version of the old Maximum Power Principle which has been under discussion for over a century, but rarely discussed among historians. If the concept is general, the self-organizational processes of history may be expected to develop towards maximum empower.

The EMERGY evaluations in this paper suggests that the Swedish ascendancy of the 17th century was derived from combining the annual EMERGY production of Sweden with other resources obtained with economic and military transactions which made the system around the Baltic Sea as a whole develop increasing organization and power.

It may be recorded that various leaders made decisions involving taxes, armies, and expeditionary forces with local and short term purposes in mind. However, the larger scale view of this is that all of Europe was developing technologies and self organizing towards larger scale operations that were together capable of processing more empower. Small actions and events consistent with this trend were reinforced and successful, whereas other actions were not. With this theory one might expect the small scale short term details to be different if people made different decisions. Yet the large-scale, long-range results could be the same.

Our evaluation showed the role of military operations in the total economy of the time. Many wars occur through miscalculation of potentials and power. With more work on past history we may improve public policies for modern times. It may be possible to measure military potentials and prowess using EMERGY and empower values to prevent wars.

It is quite exciting to see that EMERGY evaluation seems to make sense because it provides numbers that are consistent with more traditional, qualitative ways of making causal inferences about history. The solar EMERGY per units in Table 1 fit common sense about value. Silver coins have higher values than copper or iron. Human labour has higher numbers than horses, etc. These unit values will make other historic studies much easier. It will be interesting to see how similar these values are to those developed for other periods of history. Since EMERGY evaluations do not change with time, these methods provided a way to compare the buying power of the past currencies with those of today.

Scholars of history have been exceptionally thorough in gathering detailed data, perhaps because they know the value of scarce information. Detailed data are one main ingredient of science, and models of causal mechanisms are another. Whereas many believe that there are no laws of large scale causality in human affairs, in this study we perceived an emergetic systems basis for historical events. Perhaps energy systems models, EMERGY evaluation, and the maximum empower principle can open a new field of history, Energy Systems Ecology of History.

THE HISTORIAN — JAN LINDEGREN

What have we achieved by trying to measure the EMERGY-balance of Sweden around 1650? In itself

I, as a historian, am doubtful if the study in itself gives any new historical knowledge. The cost of entering the Thirty Years War was higher than the gains. Most historians, nowadays, arrive at the same conclusion using more conventional approaches and often a lot less energy. However, this may very well in itself be true, but it is nevertheless beside the point. The importance of our study is firstly that it can be used as a point of departure for other studies of historical EMERGY-balances and secondly that it is the first step towards a comparative analysis of different systems. When there is a possibility to compare Sweden around 1650 with, for instance, France at the same time or perhaps Spain at the times of Philip II, then it is more than likely that we will gain a lot of new knowledge of both systems, not least the Swedish one.

The strength of the EMERGY-analysis is that it offers a way of overcoming the problem of how one shall measure *exchange-values* and *use-values* in a society where the market is so incomplete as in the pre-capitalistic world. In modern economics this is not regarded any more as a problem. This is mostly due to the fact that the market sphere of the economy has grown immensely during the last couple of hundred of years, meaning that the values that is hard to measure in money, to some — before the environmental problems came to the surface — have been regarded as insignificant. Furthermore the economic science — Jevons, Walras Marshall and others — of the late nineteenth century is regarded to have solved the problem once and for all. This solution — neo-classical economics — is hardly hailed at all as a useful theoretical tool in the analysis of pre-capitalistic societies. Marginal utility etc. has not overly much impressed the bulk of the historians of the ancient, medieval and early modern world. But the economists themselves think otherwise and even give Nobel-prizes to each other for their efforts.

In principle the EMERGY-analysis is, just like neo-classical economy — another way of reducing all kinds of values into something basic. This time it is solar-joule instead of money. In societies where perhaps 90% of the production was distributed outside the marked economy solar-joule seems to be an interesting measurement. However both the EMERGY-analysis and the neo-classical one may lead to the same kinds of mistakes. That is to overlook the societal problems. These problems were perhaps most acute during the early modern period when new centralised states emerged all over Europe. The main problem for these states were the very fact that everything could not be transformed into something else or more precisely into money. Societies do not function entirely on solar-joules nor on market values. There are also a lot of different kinds of societal values, which are immensely important in the historical process.

EMERGY-analysis have no doubt a huge potential for historical studies. But such analysis will not revolutionise the historical science. Useful as it may be, the concept of EMERGY ought not to represent more than a new tool. Some formulations in this paper seems to indicate that it also represents something which almost amounts to a new philosophy of history. A different and perhaps also a necessary perspective — yes. A new philosophy of history — no.

THE FORESTER — ULF SUNDBERG

There is only one world and it is becoming increasingly evident that many of the serious problems facing civilization are global and do not respect national borders. The need for methods and scientific approaches that can deal with very large and complex systems is urgent. The method used in this study is one such approach. It not only mimics the interactions of nature and human economy in a realistic, comprehensive and understandable way through the use of systems language but also quantifies the flows of energy and matter and the use of resources in man's household using energy as scale. Energy is the driving force in all living systems and using the EMERGY scale is, for me, highly relevant.

My interest focuses on the role of the forests, inspired by the findings of Cottrell (1955) that the state producing the most surplus energy (energy in excess of energy used up) will gain the power and wealth in the region: "Power is a means of power". This theory is convincingly supported by Perlin (1989) who describes the role of forests in the movement of civilization from ancient Mesopotamia through Europe to 18th century North America over a period of 5000 years on four continents.

Sweden's forest resources allowed the generation of a huge quantity of surplus energy used for family needs and the production of copper, steel and tar accounting for about 90% of Sweden's export. The surplus energy from the forests embodied in these products is equivalent to about 500,000 tonne of oil (disregarding quality), an enormous quantity at that time. That this export was the major base for Sweden's war efforts is long since accepted by historians and economists. We have quantified the contribution from nature, e.g. wood, in the production of steel, cooper and tar and show the importance of the forest for Sweden's power.

But in the real world of today, market economics dominate and are more often than not the base for decisions. It disregards sunk, historical costs and applies the concept of opportunity costs. Thus, there is a wide conceptual gap between EMERGY theory of value and market economics which needs to be overcome.

In my studies of this epoch, it has struck me that our forefathers 300–500 years ago were much more aware than we are today of the profound role of energy, even if that term was not even invented then. Production efficiency in the metal industry was generally measured in output per unit energy (e.g. wood or charcoal per tonne). Lindegren (1993) has shown that one very decisive strategical element in "the wars that fed themselves" was to have control of fertile agricultural areas for feeding the soldiers and horses and to cut off the enemy for access to such areas. Also the defeat of the Swedish Army at Poltava in 1709 can be seen as a consequence of the commanding laws of energy. These insights need to be fostered today.

Sweden's aggressive war policy lasted for more than 150 years, between 1560 and 1720. It collapsed because a nation with still larger energy resources, Russia, after a long period of disorder and chaos around 1700 became organised and together with her allies was able to challenge Sweden's Baltic Empire. I have suggested (Sundberg 1992) that Sweden's ability to sustain the war efforts over such a comparatively long period as 150 years was due to the strict control by the Crown of the use of the forests for copper and steel production. Under the Crown's authority the production quota for each steel-works, 700–800 of them, was based on the sustained productivity of the surrounding forests. Even after 1720 the steel industry was intact and it more than doubled its production during the next 100 years. This contrasts with the fate of many other states of power which, as described by Perlin (1989), were not able to stop a ruthless and destructive exploitation of the forest resource, resulting in the collapse of the metal industry and a severe shortage of timber for the navy.

The study reveals that the role of the forests in a nation's economy is well described and quantified by an EMERGY analysis. I suggest that it represents a more stable, consistent and true conjuncture of a nation's state and prospects than, for example, monetary models.

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APPENDICES

Appendix 1

HISTORICAL NOTE

Commonly all the troops under Swedish high command in Germany during the Thirty Years War are referred to as the Swedish army or armies. However this has led to a clear misconception about the nature of the Swedish engagement in Germany. Most of these troops were not from Sweden at all and had practically nothing to do with Sweden and Swedes, with the exception that their commander in chief was appointed by the Swedish government. However there was a separate Swedish expeditionary force in Germany consisting of native Swedish and Finnish soldiers. This was referred to as the part of "*Riksens militie af Svensk och Finsk Nation*" (The Swedish national army) that were abroad. The expeditionary force had its own commander in chief and was maintained and used in quite another way than the 'German' armies. The expeditionary force was almost annually reinforced by Swedish and Finnish recruits who were shipped out to Germany. Some men were shipped back home — mostly officers. The expeditionary force was mainly garrisoned in towns on the German Baltic coast. This was in accordance with the Swedish war goal — to win Pomerania and hopefully some other coastal areas. It was not only soldiers that were shipped from home but also a significant portion of the money and other means that the men needed for their upkeep. The other so called Swedish armies operating in Germany could best be described as German field troops in French pay led by Swedish commanders.

Appendix 2

SWEDEN'S FOREST RESOURCE AND WOOD UTILIZATION

The role of wood for nations

The great role of forests and wood for the wealth and power of nations in the development of civilization up to the era of fossil fuels is convincingly described by Cottrell (1956) and Perlin (1989). Wood was very early a commodity for international trade. Sweden did not participate much. For example, in the period 1576–1750 the Swedish export of timber goods (excluding pitch and tar) never exceeded 6% of the total export value (Heckscher, 1936 p. L1). Export of wood to the Atlantic states was from the Baltic area and Norway. Up to about 1640 the Netherlands was the main importer but after that England took over and by 1699 imported about 70% of the Norwegian export. The political and strategic importance of the trade with wood products and masts is well illustrated by Fryjordet (1992) describing almost yearly regulations of the Norwegian trade, issued by the King of Denmark. It was for Denmark a brick in the game of power with the Netherlands and England. Similarly, Sweden's export of pitch and tar, which for the navies was of utmost importance, was also regulated by the Crown for political purposes. But Sweden gave priority to the use of wood in the metal industry for the upgrading of ore to export products like copper and bar iron for which foreign exchange could be obtained. This was absolutely necessary for keeping the navy and the troops on the European continent intact and operational.

The Swedish forest resource in the 17th century

The productive forest area and annual removals is today (Kuusela 1992):

Finland:	area		removals	million m^3
	19.9	million ha,	42.5	per year
Sweden:	area		removals	million m^3
	24.4	million ha,	50.4	per year
	44.3	million ha	92.9	million m^3 per year

The annual growth is now in the range of 140–150 million m^3. In the period 1640–1658, the area was probably about the same and after that about 6 million hectare larger. Large portions were uninhabited and not used as a wood resource. In such areas the annual growth can be regarded as nil but they represented a potential resource base. In practice, wood utilization over land distances exceeding 20–25 kilometres were probably rare as the cost was prohibitive on longer hauls, even of charcoal. The localization of the steel industry and the allowable production of each steel works was governed by the access to water power, which in general was not a problem, and wood supply within an economical zone. Later on, when the production at each steel works increased it involved an enlargement of the supply area with longer hauls.

The annual utilization 1640–1650

The annual utilization in the period 1640–1650 is assessed to about 13 million m^3 (solid) of which about 72% was for domestic use (Table 2.1). The consumption for domestic use dominates but the quantities are not well known. Kardell (1991, p.130) estimates that in the 1830's the annual consumption in Lima community was 5–6 m^3 per person. Considering the low efficiency of the stoves, the poor insulation of the houses and numbers from later periods (e.g. Joachimsson, 1910 and Hesselman, 1923) an annual use of 6.5 m^3 per person is considered as probable.

Production of salt from sea water is mentioned by Snorre Sturlason who refers to the prohibition of export by the Norwegian King Olav Haraldsson in the year 1016. Salt production occurred in the provinces of Bohuslän and Halland on the west coast which became Swedish in 1658. The water in the Baltic is too brackish for salt boiling. Early in the 16th century much Spanish salt was brought to Scandinavia on Dutch ships and salt boiling declined but

Table 2.1. *Estimation of the annual utilization of wood in Sweden, 1640–1650*

	E 6m^3
Domestic use for heating, housing, fencing etc., 6.5 m^3/capita, population 1.4 million	9.10
Mining, metal industry (Sundberg 1992), plus 0.033 for refining raw copper[1]	2.11
Ships: navy 0.04, merchant fleet 0.08 (Appendix 3)	0.12
Tar and pitch (Appendix 3)	0.60
Export of lumber, production of salt, potassium etc.	0.70
Total	12.63

1 Based on Norberg (1956).

It is assumed that at that time about 20% of the forests were economically accessible, or about 9 million ha. Thus, the removals were about 1.4 m^3/ha/year and per capita use, about 9.0 m^3/year. The present annual increment in this area is probably around 4 m^3/ha, indicating that less than 50% of its growth potential was used. But these averages are not quite adequate as the forests in the steel belt in central Sweden and for tar production in East Bothnia were at that time already rather intensively used. Also swidden agriculture, forest fires and pests depleted the forest resource. As a whole, a continuing, sustainable supply of wood was possible during the 17th century, even without extending transports from more remote forests. This conclusion is supported by Wieslander (1936). He points out that some steel foundries were closed down for reasons of wood shortage. But closing down small works for other reasons was also common. Karlsson (1990) describes the increasing problems during the 18th century for the metal industry to secure the supply of charcoal. At that time the production of steel had doubled and farmers were more reluctant to deliver the required quota.

Salt and potassium

In the period 1640–1650 the wood used for salt and potassium was rather small. Salt was a major import commodity for Sweden. In the 16th century it was 24–31% of the import value and in the 17th century about 10%.

increased for a short period towards the end of the century as the Dutch charged high transport tariffs. After about 1750, salt boiling was only done for household use. About 5 m^3 solid wood was required to produce one hectolitre of salt with a weight of about 150 kg (Lindner 1935). This figure is confirmed by Fryjordet (1992, p. 17) for Norway. Norway exported much salt up to about 1500 but from then on the salting of herring used up the whole production.

Potassium (K_2CO_3) was a Swedish export product as early as the 13th century. The major producing region was south of the Baltic with Danzig, Königsberg and Riga as export ports. In the late 17th century this production was promoted by the Crown so that in the period 1738–1747 the annual export accounted 76.8 tonne ash and 1,526 tonne potassium. It then declined because of the enormous quantities of wood required, about 3 million m^3 per year.

Birch and beech are the best tree species for potassium (Åhman 1983). Piles of wood of about 3 m^3 are slowly burned, the ash collected in bags and brought to an oven located close to a brook. The ash was lixiviated with water to remove insoluble substances. The mixture was tapped into a large boiling pot, then boiled to a thick "porridge" which was dried. To get pure potassium it was then calcined by heating so that coal and other organic matter was removed. The wood requirement is assessed to 1.5–2.0 m^3 solid wood per kg potassium. It was used for many purposes including the textile industry and for making soap and glass (account based on Tirén 1937).

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Appendix 3

A. THE SWEDISH NAVY1635–1685 AND ITS WOOD REQUIREMENTS

Sizes and dimensions of timber and masts for 17th century ships

To illustrate the requirements of sizes for ship timber, the following examples are presented from the Vasa ship, built in Stockholm 1626–28 and salvaged, almost intact, from the muddy bottom of Stockholm harbour in the 1960's.

The Vasa ship had a displacement of 1,210 tonne with a sail area of 1,275 m^2. The main mast is a composite mast with a squared pine log in the centre, 26.5 metre long on which segments of oak were nailed giving it a circular shape. Its diameter 7 metres from the butt end is 90 cm. The main mast was jointed with two successively smaller masts, the top mast and gallant (in Swedish *märsstång*, *bramsstång*), so that the height from the keel was 52.5 m.

The fore mast is the largest bole of the ship, 24.5 m long with a top diameter of 42 cm and a diameter 5.5 m from the butt end of 72 cm. Its volume is over 6 m^3. The largest log of the ship is the squared keel, 14 m long, 60 cm wide and 50 cm thick. Its volume is 4.2 m^3. The boards of oak are 10–12 m long, 30–35 cm wide and 7–10 cm thick. The largest boards have a volume of 0.4 m^3 ($=13.6$ f^3).

Masts were scaled in palms, a measure used in most countries indicating that masts were an important product for international trade. One palm was about 90 mm in Amsterdam and Hamburg (SAOL) but Fryjordet (1992, p. 66) states that in Norway it was about 8.85 cm which corresponds to a diameter of 2.83 cm. Standing mast trees were scaled in palms two feet above the root but in the trade the masts were scaled as follows:

16–17 palms 8 feet from butt end
18–19 palms 11 feet from butt end
20–21 palms 14 feet from butt end
22–23 palms 16 feet from butt end
25–28 palms 18 feet from butt end
Norwegian scaling rules from 1688, Fryjordet (1992).

Mast trees were large as presented below:
8 palms–DBH: about 25 cm over bark
12 palms–DBH: about 37 cm over bark
20 palms–DBH: about 60 cm over bark
25 palms–DBH: about 75 cm over bark
DBH = diameter at breast height

The transport of masts from the stump was usually made with yokes of oxen. Perlin (1989, p. 280) referring to an eye witness, reports of a big mast in New England, pulled by 36 yoke of oxen, which must have been a remarkable sight. Albion (1926) states that the masts from the Baltic were pulled on sledges or three pairs of axles by 8–20 yokes of oxen.

According to Perlin (1989, p. 281) masts with a diameter above 70–75 cm were not available from the

Baltic area. The mast to the large ships of the 18th century required masts with a diameter of about 90 cm and a length of over 30 m. Trees of such dimensions could only be found in the New England states. In 1634 England began importing masts from this region which gradually grew as the supply from the Baltic and from Norway became increasingly difficult and uncertain. The mast trade from New England soon gave rise to bitter conflicts between the New Englanders and England who insisted on prohibition of the lucrative export of wood to the competing sea powers. As described by Perlin (1989) the wood trade was one of the causes to the armed revolt against, and liberation from English rule, triggered by the famous Tea Party in the harbour of Boston on 16 December, 1773, and resulting in the Declaration of Independence in Philadelphia on 4 July, 1776.

Ships and Displacements

The Swedish navy was established in 1522 when Gustav Vasa bought a few ships from the Hanseatic city Lübeck to block the inlet to Stockholm, then occupied by King Christian II of Denmark, in Denmark with the affix "The Good" but in Sweden named "The Tyrant". During his reign 1523–1560 King Gustav Vasa considerably strengthened the fleet and this policy was continued by his sons so that towards the end of the 16th century the Swedish navy was one of the most powerful ones in the world (Halldin 1963 p. 53). This made it possible for Sweden to pursue an aggressive war policy to liberate Swedish trade from the Hanseatic control and to gradually involve herself in the struggle for power and the establishment of the Swedish Baltic Empire (Sundberg 1992). In the 16th century the fleet included some galleys for defense in the archipelagoes.

Table 3.1 shows the displacement of the Swedish navy at five years interval 1635–1685, on the average 30,000 tonnes. Table 3.2 shows the reinforcements of the navy 1631–1685 in size classes (ships above 100 tonne). About 73 ships were built in Sweden or in the Baltic territories; 7% were bought and 20% taken from enemies. Specification is presented in Table 3.3 (from Glete 1992 with his kind permission).

The annual reinforcement was 2.65 ships with an aggregated displacement of 1,824 tonne. Average service life was 16–17 years. Losses in battle were small, more ships were lost through wreckage. (Around 1710 Sweden began to build an Archipelago fleet, mainly to meet the threat from Russia, who was raiding the Swedish east cost).

Non-combat ships for transport and storage are not included. They were often temporarily hired for duty from the merchant fleet. For the shipping of 20,000 men from Sweden to Germany in 1635 the commander Ryning needed a fleet of 8 average sized ships, 14 smaller ones and 3 "bojorters" (Zettersten 1936).

Many merchant ships were armed with a few guns for temporary enrolment in the navy or for defense against privateers raiding the seas, often commissioned by an enemy state. British ships with supplies from the Baltic often were convoyed for that reason.

There were five big sea powers in Europe in the 17th century: England, The Netherlands, Sweden, Denmark/Norway, France and Spain, each with 35–70 vessels and a displacement of 25,000–40,000 tonne. In the late 16th century the Swedish fleet was one of the biggest. The later half of the 17th century was a period of very high naval activity. The five northern states increased their navies from 140,000 tonne in 1650 to 400,000 tonne in 1680 (Villstrand 1992). Spain was the dominating sea power during the first half of the 16th century, continuously challenged by the Dutch. The defeat of the Spanish Armada in 1588 strengthened both Dutch and English sea power and during the second half of the 17th century, the Netherlands fought three hard sea wars against England. By 1700 England had about one third of the naval force, the Netherlands and France had one third and the rest of Europe had one third. During the 18th century England further increased her strength, cemented at Trafalgar in 1805.

Table 3.1. *Sailing vessels of the Swedish navy 1635–1680. Adapted from Glete, J. Navies and Nations (manuscript)*

Year	Displacement, tonnes
1570	21,000[1]
1635	31,000
1640	28,000
1645	35,000
1650	28,000
1655	28,000
1660	23,000
1665	31,000
1670	35,000
1675	35,000
1680	21,000
(1710	60,000)

Includes vessels larger than 100 tonnes displacement

1 Considered the largest fleet of its kind in the world.

Table 3.2. *Reinforcement of the Swedish navy 1631–1685. Adapted from Glete, J. Navies and Nations (manuscript) summary of Table 3.3.*

Size, tonnes	Number	Displacement, tonnes
1501–2000	8	15,000
1001–1500	17	22,600
501–1000	62	45,100
100–500	59	17,600
	146	100,300[1]
Per year	2.65	1,824

1 bought 7%, taken 20%

Approximate service life of a ship was 16–17 years. Albion (1926) states 10–15 years with major repairs every third year for the Royal Navy of England.

Shipyards and supply of wood

The most important shipyard and naval base in Sweden in the 17th century was Stockholm. Other yards were in Kalmar, Västervik and Nyköping. A few ships were built in the Baltic territories. The location of shipyards was as close to oak forests as possible. Yards for the merchant ships were located all along the Swedish and Finnish coast, even in the Bothnia Gulf. These ships were generally built from softwood. Cederlund (1966) describes in detail the supply of wood for the man-of-war Vasa in the period 1625–1628. Late in 1624 plans and decisions were made to build four ships, and Vasa was one of them. The task was assigned to Henrik Hybertsson (of Dutch origin) and proceeded as follows:

1625–26	Procurement of trees and wood. Logging and primary conversion, seasoning of the wood
1626	Laying of the keel
1628	Launching of the ship.

The wood came from many sources. Some oak planks were purchased from the Netherlands, some imported from Königsberg and Riga, but the quantities are not known. Most likely most timber came from the Stockholm area and in particular from the coast of the province of Småland (Västervik to Kalmar).

A work force was sent out, headed by Johan Isbrantsson, for the felling of oak trees and the primary conversion. The team may have consisted of 30–40 men, shipwrights and seamen, and a blacksmith to sharpen the axes. The transport from the stump to the sea was subcontracted to the local people. (The following is anticipated by the author). The oak trees were of two completely different types: for planks and boards trees with a straight, sound bole meeting certain dimensional specifications. Compass timber for the carcass (ribs, buttocks, knees etc.) often deformed hedgerow trees or trees from pastures probably met the needs best (Fig. 3.1). Probably each

Table 3.3. *Swedish navy 1631–1685. Ships built, bought and taken (adapted from Glete, J. Navies and Nations. Manuscript)*

Period	1501–2000 tonne		1001–1500 tonne		501–1000 tonne		100–500 tonne		Total	
	N	D	N	D	N	D	N	D	N	D
1631–1635	2	3.3	1	1.4	8	6.5	19	5.9	30	17.1
1636–1640					1	0.6	2	0.5	3	1.1
1641–1645					14	9.6	15	4.7	29	14.3
1646–1650					8	5.7			8	5.7
1651–1655			1	1.2	6	4.6	3	0.9	10	6.7
1656–1660			1	1.5	7	4.7	9	3.4	17	9.6
1661–1665	1	1.8	5	6.6	1	0.8	2	0.4	9	9.6
1666–1670	1	2.3	3	3.9	2	1.4			6	7.5
1671–1675			2	2.4	4	2.6	3	0.9	9	5.9
1676–1680	1	1.7	2	2.8	3	1.8	6	0.9	12	7.2
1681–1685	3	5.9	2	2.8	8	7.0			13	15.7
Total	8 (0)	15.0 (0)	17 (1)	22.6 (1.1)	62 (24)	45.1 (16.4)	59 (35)	17.6 (9.9)	146 (60)	100.3 (27.4)

Legend: N = Number of ships; D = Displacement, tonne 10^3; ( ) = bought or taken.

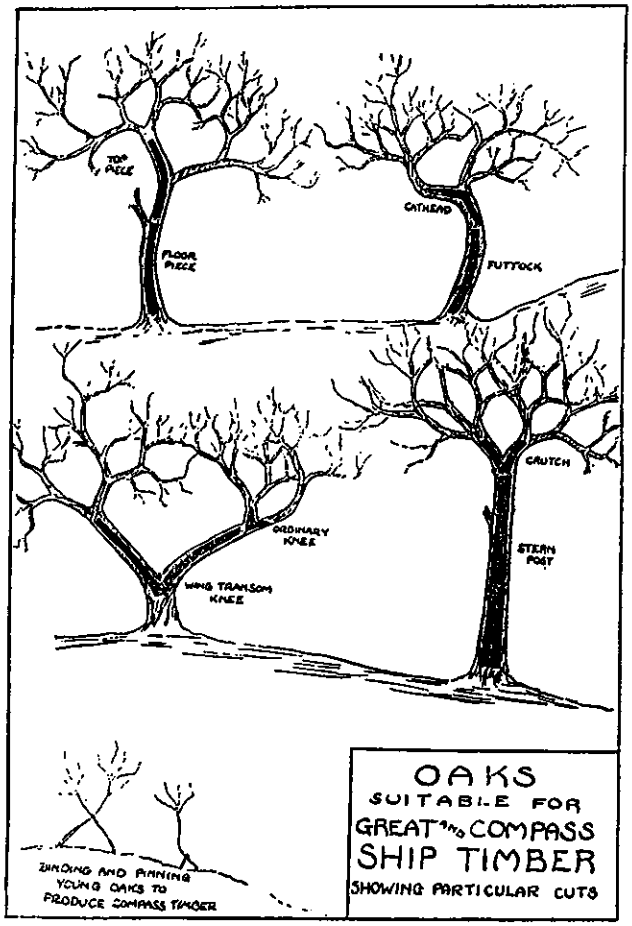

Fig. 3.1. Oaks suitable for great and compass slip timber showing particular cuts (from Albion 1926).

tree was inspected by the shipwrights and if suitable as compass timber they decided in detail how it should be cut up. Saw logs were most likely hewn on at least two sides (in Swedish huggebord) and the compass logs semi-processed at the stump to remove wood not needed for the final formation at the yard. It is fair to believe that this conversion in most cases was made at the stump to reduce transport weight and allow good seasoning of the wood. Lindner (1935 p. 174) states that from 1520, oak logs were also sawn in water mills. Unutilized parts of the tree are assumed to be used by the local people.

Masts

A wooden ship required 20–25 masts, yards and spars (Albion, 1926, ch.1). The larger ones were of exceptional size which was essential for the ship's sailing capacity. Trade of masts from the Baltic, as well as of other timber assortments for the navies, had already begun in the Hanseatic period, grew in the 16th century and was most important around 1700. The first cargo of masts from Virginia in North America was in 1609 but it took about 100 years to develop in scale, then mainly from New Hampshire, Maine and Massachusetts. Albion (1926) and Perlin (1989) both give detailed and fascinating accounts of the mast business which for the sea power nations involved both strategic and political issues of utmost importance. (As a curiosity, Albion points out that the old English name for the Baltic timber region Prussia was Sprucia, from which the term for a tree species "spruce" derives, p. 146.)

Albion (1926, ch. 1) states that a 74 cannon ship required a main mast 36 metres long and about one metre in diameter with a weight of 18 tonne. Lindner (1936, p. 173) states that in the 17th century the main mast should be 21 metres long with a base diameter of 58 cm, 33 cm at the top and a volume of 3.8 m^3. In 1746 the dimensions had increased to 30 m, 70 cm, 40 cm and 7 m^3.

The main supply of masts and timber in the 17th century was Baltic timber from Dantzig, Riga and Memel. On 20 occasions during 1658–1814, England sent fleets to the Baltic to secure this trade but paid otherwise little attention to the Baltic wars.

Cannons and arms

The number of cannons (in Swedish "*stycken*") of the Swedish navy (Table 3.4) are given in Table 3.4. Before 1640 the cannons were of bronze or copper but from then on iron was increasingly used as it was cheaper and as they could be made lighter. The weight of a 24 pounder was 1.75 tonne for an old type and 1.2–1.3 tonne for a newer one. The same cannon for the army had a weight of 0.835 tonne (Borgenstam and Sandström 1984).

It is assessed that in the period 1640–1650 the annual need of metal was 25 tonne bronze and 25 tonne iron. Hand arms for the crew included muskets, pistols, swords, broad axes, axes, pikes and partisans; the same as for the army.

Estimate of wood requirements

The estimate requires conversion factors and other assumptions for which no published documentation is known.

Method

1. Non-wood components of the fully operational ship are deducted from its displacement.
2. The balance in tonne is converted to m^3 wood, assuming a basic density for oak of 0.62 with a

Table 3.4. *The inventory of cannons of the Swedish Navy*

Year	"*Stycken*"	Sizes of cannons in 1648			
1643	1,347		Bronze	Iron	Total
1648	1,428	24 pounder	190	–	190
1658	2,500	20 pounder	–	94	94
1672	1,777	14 pounder	–	136	136
1675	1,936	12 pounder	428	–	428
1677	2,043	6 pounder	234	182	416
		3 pounder	130	34	164
	Total		982	446	1,428

(Source Zettersten 1936, p. 325).

moisture content of 20%. Result: wood built into the ship (the share of softwood is neglected but is compensated for by counting tar and pitch as wood).

3. For repairs during service life 40% is added.
4. Waste at the final formation at the shipyard (sawdust, cut-off pieces etc.) is added, 30%. Result: wood delivered to the shipyard.
5. Non-used waste at the primary conversion at the stump is added, 20%. Result: round logs used for the ship. Final number for this study.
6. Parts of the felled trees used by local people, 40% is added. Result: stem wood exploited from the forest.
7. Oak is converted to softwood equivalent by multiplying with the factor $0.62/0.45 = 1.38$ (for the EMERGY analysis).

The following deductions are made for a displacement of 1,000 tonne:

Item	tonne
ballast	150
crew with personal belongings, 350 men × 0.1 tonne	35
arms	40
steel, nails, fittings, anchor	3
food, water, firewood	12
Total	240

The balance 760 tonne is assumed to be wood with a basic density of 0.62 and a moisture content of 20% = 0.77 tonne per m^3. Wood in a ship of 1,000 tonne $760/0.77 = 987$ m^3. Add 40% for repairs $1.4 \times 987 = 1{,}364$ m^3. Assuming 30% waste at the shipyard the volume delivered to the yard is $1{,}364/0.7 = 1{,}949$ m^3. Add waste at the primary conversion $1{,}949 \times 1.20 = 2{,}338$ m^3. If 40% of the stem wood is rejected at the stump, the gross cut volume is $2{,}338/0.6 = 3{,}900$ m^3. For an annual production of 1,824 tonne the wood requirement is $1{,}824 \times 3{,}900 = 7{,}108$ m^3 as stem wood including repairs, tar and pitch. As softwood is used in the EMERGY analysis this volume is multiplied with the factor $0.62/0.45 = 1.38$ to 9,794 softwood equivalents or about 10,000 m^3. Crew: 0.30–0.35 man per tonne of displacement (Glete, 1992).

Summary: Exploited stem wood of oak 7,108 m^3
Built into the ships 2,490m^3

Remarks

The annual need may seem small. Assume an annual growth of a wood resource of 4%. Assume further that only a fraction was usable for shipbuilding because of very specific requirements (dimensions, forms: perhaps in the range of 10–20%). The total wood resource needed for a sustained supply is then $7{,}108/0.04/0.15 = 1.2$ million m^3. Consider that only forests close to the coast and navigable or floatable waterways were in reality accessible, it is not surprising that many states very rapidly exhausted their wood base and that prices were high.

Lindner (1935) states that during "later times" (probably 18th century) the wood requirements were:

116 cannon ships	4,600 m^3 stemwood
80 cannon ships	3,400m^3 stemwood
50 cannon ships	N.A.

Albion (1926) states that for a 74 cannon ship about 4,500 m^3 of oak and 570 m^3 of softwood were required at the shipyard.

B. TAR, PITCH AND THE NAVIES

World trade

Tar and pitch were indispensable products for building wooden ships and for keeping them afloat. For the naval nations tar and pitch were goods of great strategic importance, often forcing them to policy and war interventions in order to keep the trade route from production regions open.

Tar is known as a Swedish export product as early as in the 14th century but the quantities were small. Up to about 1620, Prussia was the most important production region around the Baltic Sea but from then on shortage of wood rapidly changed the situation and tar became in a short time an almost entirely Swedish product on the world market (Villstrand, 1992).

For England its dependence on supply of tar from the Baltic Sea was long regarded as unsatisfactory, especially for the Royal Navy and in the beginning of the 18th century great efforts were made for production in North America, breaking the Swedish world monopoly of more than a hundred years.

The fleets of wooden ships, both in military navies and in merchant service, increased rapidly in the 17th century. Europe's merchant ships around 1600 are assessed to a total displacement of 600,000 to 700,000 tonne and in the 1780's to about 3,372,000 tonnes. In the 1630's the Dutch merchant fleet alone comprised about 3,000 ships with a tonnage of about 500,000 tonne, requiring the building of 300–400 new ships per year (Villstrand 1992). In 1650 the Dutch merchant fleet consisted of 16,000 ships of which 6,000 were ocean going. About half of the fleet was employed in the trade in the Baltic (Halldin 1963). The total displacement of the military navies of England, the Netherlands, Sweden, Denmark/Norway and France increased from about 140,000 tonne around 1650 to close to 400,000 tonne around 1680. The demand for tar and pitch showed a parallel increase. These products had to pass through the straight of Öresund, which was up to 1658, wholly Danish but from then on with Sweden on the eastern and Denmark on the western side. The Danish Crown took a toll of about one percent of the value of the goods at a passage. The strategy of both the Netherlands and England was largely influenced by the need to keep the straight of Öresund open for the trade in the Baltic especially concerning masts, tar and pitch and not allow Denmark nor Sweden to become too powerful in the Baltic Sea. The Belt Straights were not used, as being considered too shallow and rocky. As late as in 1701, 86.5% of tar imported to England came from Sweden (Heckscher 1935, Bd 1:2, p. 436).

Production regions in Sweden

In the mid 16th century the tar export from the province of Småland along the S E coast of Sweden dominated the Swedish production (Villstrand 1992) but at the turn of the century Finland had taken the lead with the region around lake Vuoksen (export port: Viborg) and the province of East Bothnia as the main producing districts with Gamlakarleby and Vasa as the major export ports. In the mid-17th century and onwards, East Bothnia accounted for about 40% of the Swedish export. Here every farm produced about 7 barrels of 125 litre per year.

Production

The production of tar has old traditions in Finland and Sweden but the technology was greatly improved in the beginning of the 17th century when mass production took on by means of the introduction and perfection (most likely from Prussia) of the tarpit or the "tardale" (in Swedish *tjärdal*), a technique still prevailing unchanged (Fig. 3.2). The stem of pine trees of all sizes were peeled to three quarters of the circumference (*katning*) leaving a strip of one quarter to keep the tree alive, the "life strip" (*livranden*). After about three years the stem was saturated with tar. Still better was to peel off one quarter each year. A ladder was often used peeling large trees to a height of about 4.5 meters. The same treatment was applied on trees with a diameter of 4 to 8 cm for the production of tar torches, which were split up in 4 or more sectors. Logs of about 60 cm length or more were piled in the "tardale" and it was not necessary to split them in small pieces as is done with wood from stumps. The tar was tapped in barrels of 125 l. During the first phase of burning the tar was mixed with water. Then the best quality was achieved, pure and of ideal fluidity. During the last phase the tar was thick and often polluted with coal particles. The barrels were marked with these qualities. The barrels were transported to the export ports on snow, ice and on waterways, either floated or in boats. The rather flat topography of East Bothnia with an abundance of pine forest was an ideal setting. The production, requiring at least four years of production time, was performed by farmers during their slack periods of farming. The annual work cycle on the farms had two periods of relative idleness, the "lazy-summer" (in

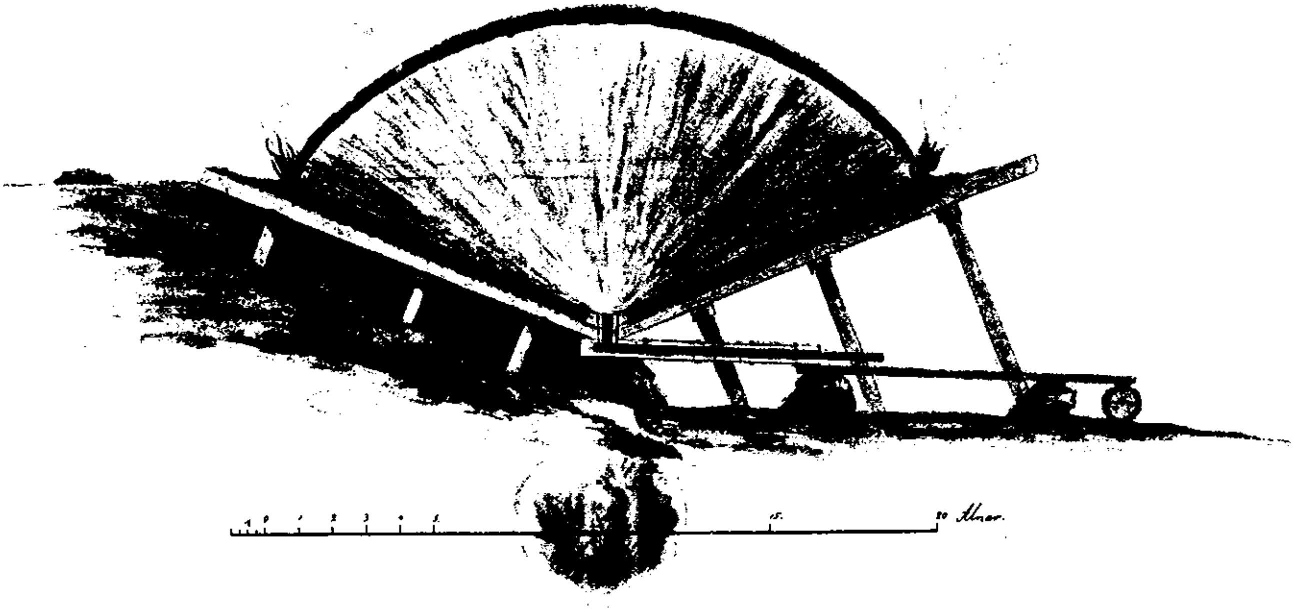

Fig. 3.2. Cross section of tar burning pit, a "tardale", according to a drawing by the director C.F. Plageman from the year 1837 (Source: Tirén 1936, p. 193).

Sw. *latsommar*) and the "winter-rest" (in Sw. *vintervila*), balancing the toil of work and the sweetness of repose. The work for production of industrial wood, charcoal and tar, fitted well into these slack periods. Increasing taxation contributed to farmers' incentive to shorten their periods of repose. It is assessed that 8–10 mandays (Villstrand 1992) were required for the production of one barrel of tar, including the manufacturing of the wooden barrel, made of spruce, and the transport to the export port.

Export

The export of tar and pitch from Sweden, including Finland is well known.

Table 3.5. *Annual export of tar from Sweden and Finland (Villstrand, 1992)*

Year	Barrels	Approx. weight tonne
1559	3,500	480
1600	18,700	2,570
1615	30,000	4,130
1641	104,000	14,300
1673–79	114,000	15,680
1684–87	128,000	17,600

Note: One barrel = 125 l, specific weight of tar about 1.1 kg. One barrel = 0.125 × 1.1 = 0.1375 tonne.

No assessment of the quantity used in Sweden has been found. It is assumed that it would be about 1,500 tonne per year. Thus, for the period 1640–1650 the annual production is estimated to about 16,000 tonne, of which 14,500 tonne was exported. The tar export from Sweden ranked third in value after steel and copper, about 10–15%, and was about double the export value of lumber.

Wood requirements energy and EMERGY analysis

Reviewing the information by Tirén (1937) and Villstrand (1992) the wood required for production of one barrel is assessed to 2.5 m^3 solid wood piled in the "tar-dale". Assessing that 50% of the stem wood was wasted and left at the stump, the annual need of wood is assessed to about 582,000 m^3 solid stem wood or about 600,000 m^3 if the wood needed for the barrels is included. This amounts to about 30% of the wood used by the metal industry. The yield of tar per unit of wood will depend on how much tar that the "*katning*" (peeling) of the stems produced. Assuming that the basic density of the pine wood increased from about 0.45 to 0.9 through "*katning*" the yield of tar amounts to about 5% of the dry weight of the wood piled in the "tardale". Petrini (1928) estimates a yield of 15–20% of the dry wood stumps which here is considered a not common maximum.

Energy analysis of tar production in the 17th century

Table 3.6. *Total annual input of direct energy in the Swedish production of tar and pitch in the period 1640–1650*

	Quality of energy	Input GWh/year
Wood	Heat	1,400.00
Animal	Power	1.16
Man	Power	0.93

Note: Basic numbers for tar and pitch 1640–1650. Wood: 600,000 m^3 2.33 MWh/m^3. Total production 16,000 tonne/year. Export 14,500 tonne/year. Used in Sweden 1,500 tonne/year. Animals: 2 workdays (0.5 kW) per barrel = 14.5 workdays per tonne, 14.5 × 0.5 × 10 × 16,000 = 1.16 GWh. Manpower: 10 mandays (0.08 kW) per barrel = 72.7 × 0.08 × 10 × 16,000 = 0.93 GWh.
(Based on Villstrand 1992; and Tirén 1937)

An EMERGY evaluation of tar production is presented in the main text, Table 9.

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Appendix 4

THE SWEDISH METAL INDUSTRY: STEEL AND COPPER

Steel and Copper

The annual production of steel (bar iron) was about 20,000 tonnes and of copper, about 2,070 tonnes with about 85% of both products exported (Sundberg 1992). The inputs to this production are summarized in the Table 4.1. The input of energy in kWh refers to direct energy. These figures are used in the EMERGY analysis in the main text to this paper.

Details of these estimates are presented in the references below (Sundberg 1991, 1992). For the refining of raw copper (about 90% Cu) to pure copper (97–99% Cu) the following additions of the figures in Sundberg (1992) are made in GWh/year: charcoal 77, animals 0.10, labour 0.13, hydropower 0.65 (based on Norberg 1956).

Silver was never a Swedish export product. An energy analysis of the silver production is presented in Appendix 5. Charcoal was at that time the energy carrier of the highest quality producing the high temperature needed for the production of metals of good quality. Charcoal represented the major en-

Table 4.1. *The annual input to the metal industry in Sweden in the period 1640–1680*

	Steel	Raw Copper	Total
Wood, m^3 solid 10^6	1.5	0.575	2.08
m^3 solid $tonne^{-1}$	75.0	288	–
MWh $tonne^{-1}$	175.0	672	–
Animals, horse days	2,800,000	391,000	3,191,000
horse days $tonne^{-1}$	140	196	–
kWh tonne⁻1	700	978	–
Labour, man days	4,750,000	1,100,000	5,850,000
man days $tonne^{-1}$	238	550	–
kWh $tonne^{-1}$	190	425	–
Hydropower, GWh	42.0	3.30	48.10
MWh $tonne^{-1}$	2.1	1.65	–

ergy input of wood energy, and required about 80% of the labour input. It was normally four forest workers on each worker at the steelworks. An EMERGY analysis of charcoal production is presented in Sundberg et al. (1991). In these estimates it is assumed that the charcoal burning in the 17th century was made with wood of large dimensions and of good quality resulting in an energy yield of about 45% and a labour input of one manday per m^3 charcoal.

The use of wood in the protoindustries of western Europe is described in the proceedings of a colloquium at Toulouse in 1990 (ISARD 1992) in which especially the papers by Plaisance and Collins present interesting overviews of the forests and protoindustries in France and Great Britain respectively.

EMERGY analysis for the production of copper and steel is presented in the main text, Table 10 and 11. Accounts on early steel production in North America are presented by Kemper (1987) and Lewis and Hugins (1983).

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Appendix 5

SILVER PRODUCTION IN SWEDEN 1500–1700

Silver was the key currency for the trade and in the European finance system. All exchange of value and the international trade was made in silver and the exchange value of the national or local coins was related to their silver content. The Swedish export of steel, copper and tar was reimbursed in silver which then was used for the financing of the wars and for imports.

The production of silver in Sweden was most important in the 16th century when the production of the Sala silver mine at Salberget peaked. It was then the major source of income for the Swedish Crown. But during the first decades of the 17th century the production of copper increased rapidly and the value of copper production during that century was constantly about 13 to 14 times higher than for silver. Even the value of the tar production was about twice as large as for silver.

However, the Crown tried with all means to increase the silver production with tax subsidies and direct support, far exceeding the value of the yield. An example is the opening of the silver mine at Nasafjell, high up above the timber line in the mountain range to Norway, close to the polar circle. It was in operation 1637–1660 with an annual output of only 36 kg.

The production of steel and copper was also supported, but to a lesser extent, but still beyond purely economic limits. This industrial policy was dictated by the great need of silver by the Swedish Crown. The supply of silver through internal production and exports of steel, copper and tar, was perhaps the most urgent factor for the financing of Sweden's exercise of power.

As for Sweden, silver was a magic metal for rulers in most countries. Heckscher (1935, Bd 1:2, p. 436) refers to a much read German mercantilist, P.W. von Hörnigk, who claimed that a production returning only 50% of its cost, gave a profit of 50% for the country.

The first Swedish production of silver was at East and West Silvberg in the Norberg county but the quantities were small. Around 1510 the silver ore at Salberget was discovered and rapidly exploited under the control of the Crown. Its output peaked in the mid-16th century with a yield of about two to three tonnes per year, at that time the most valuable income of exchange for the Crown with an economy largely based on exchange of values in use. The rich ore at Salberget was rather soon exhausted and the Swedish annual production of silver in the period 1640–1650 can be estimated to about one tonne, about half of the production one century earlier (Heckscher 1936, Bd I:2 437–439).

The silver production at Salberget in Sala

Silver, one of the noble metals, has a specific weight of 10.5 and a smelting temperature of 960.8°C. In Sweden it appears as a sulphide, Ag_2S, in galena (in Swedish blyglans). In addition to lead the ore also contains zinc, gold and other metals in minute amounts. Lead has a specific weight of 11.4 and a smelting temperature of 327°C. Native silver can also be found, one piece of 680 kg was once found in Norway, and one of 1,026 kg in Sonora, Mexico. Today, silver is obtained as a by-product in lead and copper production in Sweden.

The production in Sala in the 16th and 17th century involved the following steps:

- Mining, using wood
- Crushing, assorting and washing
- Roasting of the ore, using wood
- Smelting, using charcoal
- Refining, using charcoal

Already in the mid-16th century the crushing was partly made with water powered hammers but before by hand. The silver content of the ore was probably about 1% (Engelbertsson 1987), the richest ore found in the 16th century. About 60–70% of the ore was lead, the balance was sulphur and other materials. The production peaked in the period 1537–1548 with 3,420 kg per year (Heckscher 1936, p. 163). Gustav Vasa kept most of this production in his treasury but this stock was completely used up by his son, Erik XIV, for the seven year war 1563–1570. Also Erik's spectacular coronation was a very costly affair. In the period 1641–1650 the production was about 750 kg per year.

There is rather rich documentation of the silver production in Sala, which is better and more factual for the 16th than for the 17th century. However, the records are fragmentary, often with inconsistencies difficult to explain. None of the authors have ventured to consolidate these records into numbers for the inputs of wood, animal power and manpower usable for an energy analysis. Such an attempt follows.

The Crown, claiming regale of the ore, exercised a strict control of the silver production in Sala, which was performed partly by the Crown, partly by a large number of "mountain men" (in Swedish *bergsmän*). The *bergsmän* were organized in a *Bergslag*, an agrarian-based cooperative, leasing the right to mine from the Crown. Granström (1940, p.142) states that in 1540 there were 279 *bergsmän* and Norberg (1978, p.84) gives the number 328. The smelting and refining was made in small ovens. The metallurgic process was not particularly efficient as much of the silver in the ore could not be extracted. Engelbertsson (1987) estimates that 30–50% was lost at the smelting. The silver was dissolved in the lead, which sometimes had to be added, resulting in "*verkbly*" containing a small amount of silver, perhaps 3–5%. The next phase (*avdrivning*) involved the evaporation of lead so that most of the silver could be taken out of the mixture. An energy analysis is presented below, based on an epitomization of the fragmentary information in the cited literature. It involves a crude assessment of averages from a very patchy data base.

Energy analysis of the silver production in Sala in 1537–1548

Wood and charcoal

Mining. The following figures for mining derives from Granström (1940, p. 193) for the year 1552:
12,300 barrels of ore yielded 11,453 "*lödig mark*" à 0.21 kg silver.

kg silver per barrel	0.21 × 11,453/12,300 = 0.20.
Barrels per year	3,420/0.2 = 17,100 or 57 barrels per day assuming 300 work days per year.

Wood for mining:
0.5 to 1 "*famn*" barrel (1 *famn* = 2.73 m^3 piled wood).

Assuming a solid content of 55% the consumption was:
low 17,100 × 2.73 × 0.5 × 0.55 = 12,800 m^3 solid per year
high 17,100 × 2.73 × 1.0 × 0.55 = 25,700 m^3 solid per year

Average: about 20,000 m3 or 20,000/3,420 = 5.8 m^3 solid per kg silver.

Smelting. For smelting Granström (1940, p. 416) states a consumption of 16–18.7 hl per halfbarrel. (The volume of a halfbarrel is unclear, it is here assumed that it was 50% of a barrel). Annual consumption:
low 2 × 17,100 × 0.16 = 5,470 m3 charcoal = about 5,470 m^3 solid wood
high 2 × 17,100 × 0.187 = 6,400 m^3 charcoal = about 6,400 m^3 solid wood

Granström (1940, p. 352) gives the following measures:

1 barrel of ore	2.12 hl
1 barrel of wood	2.85 hl

1 halfbarrel 1.35 hl
1 hl ore weight about 140 kg
Average: about 6,000 m3 solid wood as charcoal per year or 6,000/3,420 = 1.75 m3 solid wood per kg silver. Add 5,000 m3 for constructions at the mine, at dams etc.
Total wood consumption: 7.0 + 2.1 = 9.1 m^3 per kg silver or 31,100 m^3 wood (solid) per year.

Labour

Figures on the labour force are very scarce and uncertain. The large number of "*bergsmän*" is confusing. Norberg (1978, p. 10) makes a "crude guess" that 1,000–2,000 were employed at Salberget in the 1530's and 1540's. Granström (1940, p. 205) states that in 1565 there were 250–300 employees and in 1583 (when the production had declined considerably) 107 persons of which 17 were women. Engelbertsson (1987, p. 15) says that 1,000 persons were employed around 1540. For mining and smelting 1537–1548 we assume 400 men working 250 days per year = 100,000 mandays, or 1,000 men working 100 days per year.
Estimate for the total silver production:
Supply of wood: 25,000 m^3,
0.7 mandays/m^3 17,500 mandays per year
Supply of charcoal: 6,000 m^3,
1.0 mandays/m^3 6,000 mandays per year
Mining, smelting, refining: 400 men,
250 workdays 100,000 mandays per year

Total 123,000 mandays per year or 36 mandays per kg silver.

Animal power

(HD = horse or oxen-days)
Haulage of wood to the mine: 25,000 m3 × 0.2 HD = 5,000 HD
Haulage of wood to the "kolmila" and hauling of charcoal to Sala: 6,000 m3 × 0.4 HD = 2,400 HD
Hoisting up water and ore from the mine, miscellaneous transport of ore and wood (adapted from Granström, 1940, Table XVII, p. 356) 20,000 HD

Total 27,400 HD

or 8 HD per kg silver

The haulage of wood and charcoal was made on snow and ice during the winter and required about 100 horses. At the mine horses were used the year round, probably requiring about 100 horses.

The inputs into silver production compared with copper was 30–66 times higher per unit weight (Table 5.1). If the inputs were proportional to the metal content of the ores (1% and 4% respectively), the ratio would be 25. The following observations may explain the difference:

(i) the metallurgic process for silver was more complex, less efficient and performed in a smaller scale;
(ii) the organization and control of the production of copper was better.

For the period 1640–1650, the following changes are anticipated:

(i) the silver content in the ore had decreased
(ii) the metallurgic process was the same but its efficiency was somewhat, but not much, better
(iii) water power for hoisting from the mine, for the crushing of the ore and for powering the bellows, was in use since about 50 years.

As few data are available or can be derived for an estimate of these changes (except for water power, see below), it is assumed that the influence of these changes are in balance.

An EMERGY analysis of the silver production in the mid 17th century is presented in the main text, Table 12.

Note: *Estimate of hydropower in* 1640–1650

The estimate of hydropower refers to the dam at Långforsen using the power at the mine. Engelbertsson (1991) says that water power was used as early as the beginning of the 16th century for the crushing of the ore and for washing. Water power was also used for the bellows at the foundry at Sala Dam. These uses are included in the estimate below.

Drainage area 85 km^2
Annual run off 0.3 m3/m2. 0.3 × 85 E6 = 25.5 E6 m^3 = 0.8 m/s

Capacity of the water magazines 16.41 E6 m^3, 63% of the run off, allowing a year round flow.

Fall height used for water wheels 9.8 m
Potential energy 9.8 × 25.5 E 9 × 2.724 E-6 = 0.68 GWh/year

Efficiency of water wheels: fall height loss 40%, of water 40%, transforming energy to power 50%. 0.60 × 0.6 × 0.5 = 0.18 or 18%.

Net power on the axle: 0.18 × 0.68 = 0.122
for 3.420 tonnes 0.122 GWh/year

Table 5.1. *Energy analysis of silver production. Total direct input per year at the Sala mine in 1537–1548, compared with the inputs into copper and steel production, per tonne*

	Wood[a] MWh	m^3	Labour[b] MWh	manday	Animal[c] MWh	horseday
Sala mine, silver, total	72,000	31,000	99	123,500	137	27,440
Comparison[d]	MWh/t	m^3/t	MWh/t	manday/t	MWh/t	horseday/t
silver	21,000	9,100	29	36,100	40	8,000
copper (raw)	672	288	0.425	550	0.978	196
steel	175	75	0.190	238	0.700	140

Note: a 2.33 MWh/m^3. b 0.08 kW, 10 h shift. c 0.5 kW, 10 h shift. d Numbers for copper and steel from Sundberg (1992, Table 9).

The estimate above results in 14 kW. Sundquist (1974) states that 39 HP was produced by the water wheels. If the water wheels were running 50% of the time, they produced $2 \times 14 = 28$ kW which is close to Sundquist's figure. The base data for the estimate of hydropower were provided by Stig Gustafsson, Avesta. Table 5.2 gives ratios for the inputs into copper, silver and tar production in relation to steel production as basis.

Table 5.2. *Ratios for the inputs of direct energy per unit weight in the metal industry. Steel = 1*

	Wood	Labour	Animal	Hydropower
Steel	1	1	1	1
Copper (raw)	3.8	2.3	1.4	0.78
Silver	121	151	57	17
Tar	0.50	0.30	0.10	–

Note: Values for steel and copper is for the period 1640–50 but for silver for 1537–1548 when very little hydropower was used (here neglected).

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Appendix 6

LAND, LABOUR AND INFORMATION GAINED FROM THE WARS

A. Emergy of acquired land

The territorial gains of the Baltic Empire were:

Southern territories:

province of Blekinge	2,909 km^2
province of Bohuslän	4,450 km^2
province of Halland	4,754 km^2
province of Skåne	10,908 km^2
isle of Gotland	3,001 km^2
Sum	26,022 km^2

Average rainfall 800 mm of which evatranspiration 400 mm.

Western territories:

province of Jämtland 34,160 km^2

EMERGY evaluation:

Southern territories:

$(26{,}022\ km^2)(100\ ha/km^2)(3.64\ E14\ sej/ha/yr) = 9.47\ E20\ sej/year$

Western territory:

$(0.3\ m)(1\ E4\ m2/ha)(1\ E6\ g/m3)(5\ J/g)(1.82\ E4\ sej/J) = 2.73\ E14\ sej/ha/yr$

$(34{,}160\ km^2)(100\ ha/km^2)(2.73\ E14\ sej/ha) = 9.33\ E20\ sej/year$

Sum:
EMERGY production
9.47 + 9.33 = 18.80 E20 sej/year
acquired land 6.02 E6 ha

B. Emergy of import of people

During the 16th and 17th century Sweden pursued a very active policy to attract Europeans for the development of her economy and culture, especially during the first half of the 17th century. Sweden's expanding economy and international trade with highly demanded products made the country, increasing in power, an attractive resort for enterprising and skilful persons of all categories. The chaotic conditions, political unrest with endless warfare and religious conflicts contrasted sharply with the stable and peaceful conditions in Sweden, which at that time was one of the best organized and administered nations in Europe (Heckscher 1936, Bd I:2, 269).

Foreigners were well received in Sweden, very few returned to their home countries and by the following generation became fully integrated in the Swedish society. They all accepted the two absolute demands: loyalty to the Swedish Crown and conformity to the religion. Heckscher (1935 Bd 1:1, 110–114 and Bd 1:2, 360–380) gives a very comprehensive description of the large inflow of foreigners and their importance in advancing the Swedish state.

The estimate is restricted to persons drawn to Sweden from the rest of Europe with skills and knowledge higher than that of a skilled Swedish worker.

The EMERGY value of a skilled Swedish worker is estimated to 56 E15 sej/year (Table 7 in main text). We assume a higher EMERGY value of an imported craftsman, 100 E15 sej/year, and allocate escalating values for higher level of proficiencies as indicated in the table below.

The number of imported persons of superior skills and knowledge is a crude estimate for the mid-17th century based on information on people recruited for the metal industry (vallons) and other information provided in historical publications.

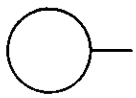
Category	Imported persons/yr	EMERGY Value/person	EMERGY Imported /yr
Craftsmen	50	100 E15 sej/yr	5 E18 sej/yr
Technicians	50	1 E17 sej/yr	5 E18 sej/yr
Merchants	15	3.3 E17 sej/yr	5 E18 sej/yr
Officers	10	5 E17 sej/yr	5 E18 sej/yr
Entrepreneurs	10	5 E17 sej/yr	5 E18 sej/yr
Artisans	5	1 E18 sej/yr	5 E18 sej/yr
	140		0.3 E20 sej/yr

(This estimate results in an influx of 7,000 skilled labourers over 50 years).

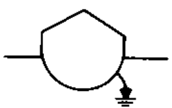
Appendix 7

SYMBOLS OF THE ENERGY LANGUAGE TO REPRESENT SYSTEM STRUCTURE AND FUNCTION (Odum, 1993).

Energy circuit (Chapters 1–3). A pathway whose flow is proportional to the quantity in the storage or source upstream.

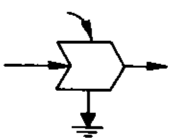


Source (Chapter 7). Outside source of energy delivering forces according to a program controlled from outside; a forcing function

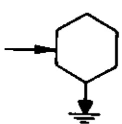


Tank (Chapter 3). A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.

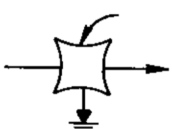
Heat sink (Chapter 7). Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



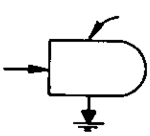
Interaction (Chapter 8). Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



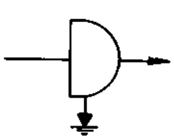
Consumer (Chapters 9 and 20). Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



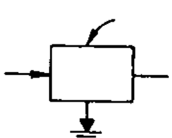
Switching action (Chapter 6). A symbol that indicates one or more switching actions.



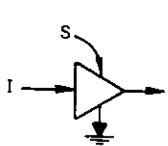
Producer (Chapters 8 and 19). Unit that collects and transforms low-quality energy under control interactions of high-quality flows.



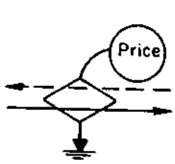
Self-limiting energy receiver (Chapter 10). A unit that has a self-limiting output when input drives are high because there is a limiting constant quantity of material reacting on a circular pathway within.



Box (Chapter 6). Miscellaneous symbol to use for whatever unit or function is labeled.



Constant-gain amplifier (Chapters 8 and 9). A unit that delivers an output in proportion to the input *I* but changed by a constant factor as long as the energy source *S* is sufficient.



Transaction (Chapter 23). A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed). Price is shown as an external source.