LESSONS FROM THE DEVELOPMENT OF WATER MILLS IN THE EARLY MIDDLE AGES FOR THE FUTURE OF FUSION. - LESSONS FROM THE HISTORY OF TECHNOLOGY.

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1. Introduction:

Political scrutiny of the R&D efforts for fusion makes it desirable to clarify the possible role of fusion in future energy markets. First attempts in this direction were made by different groups [1]. To support this work it is of fundamental importance to understand the structure and mechanisms of technological change. First step has to be an in depth investigation of historic developments. The Max-Planck-Institute für Plasmaphysik did organise in summer 2000 a workshop in Greifswald on the history of energy [2]. The workshop did span the whole time horizon from the first use of fire by humans to the most recent developments in nuclear and solar power. The workshop was a basis for the work presented here. Two major technological transformations should be discussed in the following as examples: the diffusion of the water mill and the beginning of electrification. Some first implications on fusion are presented at the end.

2. The Water Mill

The water mill is one of the most striking objects to study technological change because it took many centuries before the water mill, which was invented in the antiquity, was widely used. The Roman architect Vitruv describes already in his book (10,5,2) the design of a water mill [3]:

...The same principle is involved in driving water-mills, where everything else is the same apart from a cogwheel fitted to the one end of the axle. The cogwheel is mounted vertically upright and rotates apace with the water-wheel in the same direction. Fitted horizontally to the cogwheel is a larger one that enmeshes with it. The cogs of the cogwheel fitted to the axle thus cause the millstone to rotate by setting the cogs of the horizontal cogwheel in motion. A funnel suspended above the machine admits the grain, which is ground to flour by the same rotation....

Archaeological evidences exist in Barbegal close to Arles where a Roman military camp was supplied by a water mill [3]. Although there was already an increasing use of water mills in the late antiquity, the real boost came not before the early middle ages [4]. Historians identified a number of reasons for the delayed introduction [4]:

Settlement structure: the Roman farm was sited on the top of hills with no access to flowing water in contrast to the Frankonian settlements in valleys.

Feudalism: the introduction of feudalism in the middle age with the typical structure of a farm in the centre of numerous small and dependent farms offered a large enough demand for the capital intensive investment of the water mill.

New agriculture: the introduction of the three-field system.

Nutrition: the early middle age saw a transition to more grain in the average nutrition.

Demographic increase: the early middle age saw an population increase, combined of course with an increase in food demand.

New attitude towards manual labour: the early orders of the middle age (Benedictine) did value manual labour and labour in general more favourable than the antique societies did (ora et labora).

This examples proofs that a technology does strongly dependent on the social, economic and technological environment it is placed in. Just the demand for mills, which was already existing in the antiquity, was not enough. Any prospective modelling work needs to take account of this example. A first attempt in this direction is to describe technologies in "clusters" [5]. Only the combination of increased demand for grain, feudalism, three-field system and the water mill became a success. Identification and description of the development of the social, economic and technological environment is as important as the description of the technology itself.

3. Electrification

Electrification is of prime importance for every modern economy, a fact which can best be visualised by the strong interdependence of the increase in electricity demand and economic growth [6]. The beginning of the electricity system is connected to a number of key inventions like the investigation of induction by Faraday in 1831 and the introduction of the dynamo-electric generator by Siemens in 1866. All these findings and inventions laid the basis for the later systems. Still Edison deserves to be considered as the key inventor because he did not only invent one of the key stones, he combined everything to a complete system from the generators up to the users [7]. The major step here was the qualification of the light bulb which served as first wide spread application of the electricity. In 1882 Edison started his first electricity utility in Pearl Street. In the first stage not more than four hundred lamps were supplied with electricity. The whole grid covered not more than 1 square mile [7]. As is depicted in figure 1 for the city of Berlin it took a number of decades before all households were connected to the grid. The long lead time is mainly explained by the fact that the energy service "lightning" was supplied by another system, namely the city gas. These systems form the beginning of the nineteenth century were installed in nearly all bigger cities and already in some smaller towns. The cost of light from city gas was much cheaper than from electricity when the electricity utilities were founded. Why could electricity still enter the market? First of all it offered some advantages: no emissions in the houses, less heat production, easier handling, more safety. A small group of customers was willing to pay much higher prices in exchange of these advantages. First customers in Berlin were banks, theatres, restaurants and hotels [8]. Prices for electricity and light bulbs and so on did decrease in the long run due to learning and scaling effects. Completely new applications for electricity were found in stationary motive power replacing steam engines and in traction power driving streetcars. The massive introduction later on is explained by the on-setting learning effects which in the end made electrical light cost competitive with gas light and led to the replacement of the later. The underlying structure is very essential for numerous changes in technology. A competing innovative technology is first too expensive to win considerable market shares but serves a "niche" market. By increased production experience is gained which leads to a cost reduction and to a considerable penetration into the market.

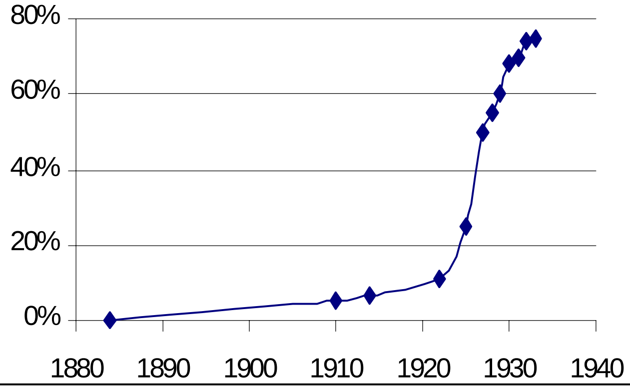

Figure 1: Percentage of households in Berlin connected to the electricity network [8].

4. Implications for fusion

The historic examples indicate how technologies might diffuse in space and time and how they improve their performance via learning. From the diffusion patterns we can already infer two important conclusion: 1) fusion will not supply bulk power before the end of the 21st century just because it takes such long times to set up numerous plants. This conclusion is of course of striking importance for the debate on climate change 2) the spatial diffusion might even be more pronounced if the fusion community does not succeed in incorporating in the technological learning process countries like China and India which will have the most pronounced demand for new plants in this century. These countries should therefore be involved in the construction of a device like ITER and especially the accompanying technology programme should be partly done in these countries. Another factor in the introcuction of a new technology is posed by the learning process. The performance of technologies does strongly improve with increased use, at some point the electrical light was not only more comfortable than gas light, it was even cheaper. But learning does only happen if installations are constructed and operated. In a lot of the prospective energy system models [1], the model has a perfect foresight and does anticipate the learning process and does therefore install a technology at a certain point in time even if it is not really cost competitive by then. To assume that the actors in real life like utility managers, bankers and politicians have the same foresight is highly questionable, especially they have usually very different time horizons for optimisation. The way out of this problem in the case of the electric light was the "niche" market, "luxury" lightning. The possible "niche" market for fusion is difficult to identify since fusion would compete in the bulk market base load electricity against the established technologies.

But even more important is the question, if fusion will fit into future technology clusters. As was shown for the water mill, only if this is the case the technology will find widespread use. Growing importance of the share of electricity, growing energy demand, increased number of megacities with high density power demand, increasing environmental concerns, need to come to closed material cycles are all trends which make it likely that fusion will fit pretty well in future technology clusters. More refined work in this direction is currently undertaken in the EU VLEEM (Very Long Energy and Environmental Model) project. The project tries to identify possible future technology clusters and to describe the path which can lead into the described future.

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