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Hvelplund, Frede

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Frede Hvelplund[1]

Department of Development and Planning, Aalborg University,
Fibiger Straede 13, DK-9220 Aalborg, Denmark

Abstract

Since 1976 a ”Green energy cluster” consisting of renewable energy technologies such as wind power, solar energy and biomass technologies, and energy conservation technologies has developed in Denmark. The export of these technologies has increased from 540 mill. ECU in 1992 to around 5000 mill. ECU in 2002 and the employment have increased to around 25000 persons. This sector consequently is one of the main reasons why the Denmark had a balance of payment surplus of 4800 mill. ECU in 2002 and a relatively low unemployment rate.
But which were the main reasons behind this development of a “Green Energy Cluster”? This is the main question to be dealt with in this paper.
The main agents were the grass root movements within renewable energy, the Parliament, the medium scale production companies and the energy companies.
In general the energy companies regarded the new “Green technologies” as competitors to their large power plants based upon coal and oil, and tried to slow down and/or hinder the “green innovation” process. The success was achieved by an active collaboration between some politicians recognising that an active energy policy was necessary and possible, private construction firms and an energy grass root movement. In this process a set of very concrete institutional reforms were established during the eighties and the nineties, furthering the “Green innovation “ development process.
This paper deal with the innovative political process developing the institutional reforms as well as a description of a set of concrete institutional reforms furthering the innovative development.

Key words
Energy policy, energy planning, technological innovation.

[1] Tel.:+4596358380;fax +4598153788.
E-mail address: Hvelplund@i4.auc.dk

1. The Danish example of democracy and "Green innovation[2]"

The goal of Danish Energy Planning include a 20% reduction of greenhouse gas emissions between 1988 and 2005 and 50% before 2030. Technical scenario analyses have shown that achieving this goal requires the introduction of massive energy conservation measures, renewable energy technologies and combined heat and power systems (CHP systems). This again has as its consequence, that the necessary techniques do not "fit" into the organisational structures of today's energy system, with its links to the fossil fuel organisations and techniques, and its sectored divisions of heat, power and transport organisation.

Therefore it is not surprising; that the new techniques within combined heat and power (CHP) and renewable energy did not develop within the existing fossil fuel based energy organisations. On the contrary these techniques wind turbines and decentralised CHP plants were introduced and implemented by grassroots organisations and local heat companies, despite strong resistance from the established energy companies. The process was that grassroots movements and local small heat co-operatives were arguing in the media and "lobbying" for the establishment of new reforms at the central level to support these new techniques. Subsequently Parliament let itself be inspired and made new laws, which supported the introduction of the new techniques. After the introduction of these new reforms, the local heat and wind turbine co-operatives would then implement the technique. The process can be named a "bottom up-top down-bottom action" process, which has nothing to do with a rigid central planning procedure, but is more of a procedure, by means of which the grassroots organisations, the general public and local heat companies by Parliamentary intervention are given the opportunity to introduce and implement innovations in the energy scene. We call this process a process of ***innovative democracy***, and it is developed by introducing a set of measures, which we here will define as ***political liberalisation.***

The above-described innovative democracy has brought some remarkable developments within wind power and CHP in Denmark. In 2001 wind power supplying 15% of total electricity consumption and more than 40% electricity was supplied from wind power and combined heat and power plants (CHP). At the same time the power efficiency of the power plants has been increasing constantly.

All together the total production by Danish Wind Turbine manufacturers rose from around 200 MW/year in 1991 to around 2000 MW/year in 2001, and the Danish export of wind turbines amounted to about 2700 million ECU in 2001. The export of the "Green cluster " of energy technologies linked to the Danish energy policy (including wind turbines) increased from 530 mill. ECU in 1992 to 4700 ECU in 2001. Amongst others linked to this development Denmark went from a deficit on the balance of payment in the eighties to a surplus of almost 5000 mill. ECU in 2001. At the same time unemployment rates went down from around 9% in 1992 to around 5% in 2001.

So the Danish energy policy was one of the most important causes behind the relative success of the Danish economy in the nineties. In the following we will take a closer look upon this development.

[2] The concept "Green innovation" is used for a process, where a systematic transformation, from fossil fuel technologies to energy conservation and renewable energy technologies, is taking place.

2. The wind power development

According to the ministerial plan wind power should cover around 20% of the electricity production in 2005, and 50% around 2030.

The wind power production cost at a good coastal site has developed from around 14 EUR/C per kWh in 1984 to 8 EUR/C per kWh in 1991 and around 5 EUR/C per kWh in 2001.
The wind power *regulation regime* has been of the type where buyers of windmills receive a fixed price from the electricity companies and a fixed public service payment for CO2-free electricity production from the Government. This is here termed a *"Political price-/amount market"* [1] system**.** This system motivated the producers to lower their production prices, as they were in a situation where more windmills could be sold if the prices of wind turbines decreased.

The wind turbine industry did not develop out of a situation that allowed the existing monopoly market to act on its own. If anything, there was a systematic public interference in this monopoly market, breaking its "barrier to entry" institutions and opening the door for the wind power technology. By means of an array of institutional reforms, an increased freedom to enter the market was established. Examples of such reforms include the following:

The reforms back in the eighties, and their political background can be shortly described within the wind power field. Initially there was:

- A 30% investment subsidy
- Utility obligation to buy wind power at a price equal to 85% of the price paid by consumer using a 20,000 kWh/year
- A right to produce up to 7000 kWh wind power without income tax payment
- The establishment of a public wind power test station at Risø Research Centre
- Spare capacity in the machine industry
- A motivated population

In this phase, lasting until around 1992, more than 3000 co-operative wind turbines were installed. Typically, a co-operative wind turbine has between 20 and 40 owners. This means that around 1990, there were between 100,000 and 150,000 owners of wind turbines in Denmark. Among other elements in the process, this was the result of a discussion in the organisation for renewable energy (OVE), a green grassroots organisation (NGO), which fought for this co-operative model. This model managed to secure very stable public support for wind power and it made this very vulnerable industry survive during the lean years, with very low export between 1987 and 1991.
Since 1992, the development has been supported by a steady increase in the export markets, combined with the development of larger wind turbines (600-2000 kW) and a 30-40% decrease in kWh prices.
The preconditions for the above development were:

At the political level,
- Efficient grassroots movements: especially the Organisation for Renewable Energy (OVE), and the anti nuclear movement (OOA).
- A rather open and active public debate.

- A specific balance in the Parliament, with small non-corporate parties having some power.
- A situation where the energy companies systematically worked against innovative renewable energy technologies.

At the cultural level,
- A tradition for wind power. The "modern" 200 kW Gedser Wind Turbine was closed down in the late 1960's, so the technology was still "recent". Prior to this, Poul La Cour had established 2-6 kW direct current electricity generating wind turbines around 1900. By 1916, there were 1300 of these turbines in Denmark [2]. A successful tradition for consumer co-operatives followed within many sectors.

At the industrial basis level
- An industrial structure, with many small (agricultural) machine factories.
- Collaboration between the State financed Risø Test Centre and private industries.

3. The development of decentralised CHP in Denmark

By around 1988, all cities in Denmark with a population above 60,000 inhabitants had combined production of electricity and heat ("combined heat and power" (CHP)). These CHP systems are largely coal based. Back in 1975, there had been a discussion of establishing CHP units in the smaller cities. But the utilities, in agreement with the Ministry of Trade, which at that time was in charge of the energy area and opted for nuclear power, did not want to take this possibility into consideration.

The grassroots organisations, OVE and OOA, argued for decentralised CHP, as it was an alternative to nuclear power. The Utilities, the Ministry of Trade, and later, the Ministry of Energy argued that CHP in small cities was not technically possible, and if at all possible, it would be too expensive. Furthermore, even if it was technically possible and economically feasible, the potential was so small that it would be a waste of time to discuss it.

As late as 1988, the potential for decentralised CHP in Denmark was considered by the authorities and the Utilities to be, at most, 450 MW. In 1989, a new Minister of Energy came into office, and "suddenly" the next energy plan, "Energy 2000" [3], showed a potential of between 1400 and 2000 MW with regard to decentralised CHP, including industrial CHP.

Different institutional preconditions were established, including the utility obligation to buy electricity from CHP plants according to "avoided cost" pricing for electricity sold to the grid based upon the principle of long-run marginal costs (LRMC). Furthermore, a public CO2 subsidy of 1.3 EUR/Cent/kWh sold electricity from CHP plants based on natural gas and a municipal warranty linked to financing the plants was introduced.

These institutional reforms had an enormous effect. From 1990 to 2001, the power productions from decentralised CHP units increased from 1% of total electricity consumption to more than 30%. Of these decentralised CHP units, 60% are organised, as co-operatives owned by the residents in a small town or village. The units have between 0.5 and 5 MW electrical capacity and are mostly fuelled by natural gas.

Strong resistance from the utilities - and, for many years, also from the central administration - has characterised the *political* process behind the introduction of the necessary institutional reforms. The policy has been a "bottom-up" generated policy established through considerable public pressure from grassroots movements, local heat co-operatives and some members of Parliament.

But what are the causes behind the resistance to change within the existing uranium and fossil fuel based power companies? That's the question in the next section.

4. The character of the technological change from fossil fuel based- to "green energy" technologies- a case of path dependency

The alternatives to uranium-, large coal-, oil-, and gas-fired power plants are electricity conservation, renewable energy and cogeneration technologies. Some of the differences between these new "sunrise" technologies, and the old "sunset" technologies are described in Table 1 below.

Old techniques "Sunset technologies"	New techniques "Sunrise technologies"
1) Based upon a high level of fossil fuel and uranium consumption.	(1) Based upon energy conservation, renewable energy and integrated efficient energy supply systems.
2) Technical solutions are not contextually adaptable.	(2) Technical solutions differ from place to place.
3) Implementation in single purpose organisations.	(3) Implementation in multipurpose organisations.
(4) Sectored energy systems.	(4) Integrated energy systems.
(5) High degree of asset specificity; long technical lifetime, high capital costs and large strong organisations.	(5) High asset specificity, medium long technical lifetime, moderately strong organisations.
(6) Historically strong from a political point of view.	(6) Historically weak from a political point of view.
(7) Mostly using known techniques.	(7) Often demand new techniques.
(8) Often linked to existing knowledge.	(8) Often require new knowledge.
(9) Often based upon existing organisations.	(9) Often require new organisations.

Table 1. Institutional characteristics of the "Sunset" and "Sunrise" technologies.[4]

The different characteristics at many levels of "sunrise" and "sunset " technologies alternatives indicate that the new technologies do not fit well in the organisation of the old fossil fuel and uranium technologies. This means that the organisations linked to these old technologies will be ill equipped to compete in the arena of the new technologies.

Consequently, one might expect heavy organisational resistance from the old technologies against the new technologies. This assumption has been confirmed in the Danish case over the last 25 years. This conclusion will be enforced, when discussing the value -added changes for old and new organisations, when participating in this radical technological change.

The value-added chain and the change from "sunset" to "sunrise" technologies

A main theoretical cognition here is that the motivation for innovation varies from firm to firm, and that this variation amongst others is a function of cost- and value-added structure.

The value-added chain of uranium/ fossil fuel based systems

The question is what are the general characteristics of the present fossil fuel and uranium based electricity supply systems, which at present, controls between 80% and 90% of the world's electricity market. This is a crucial investigation, as we are dealing with a system which, to a very large extent, has to be replaced with energy conservation and renewable energy systems within the next 20-40 years. Figure 2 illustrates the value-added flow in these systems; here they are represented by the Danish system based upon large coal-fired power plants.

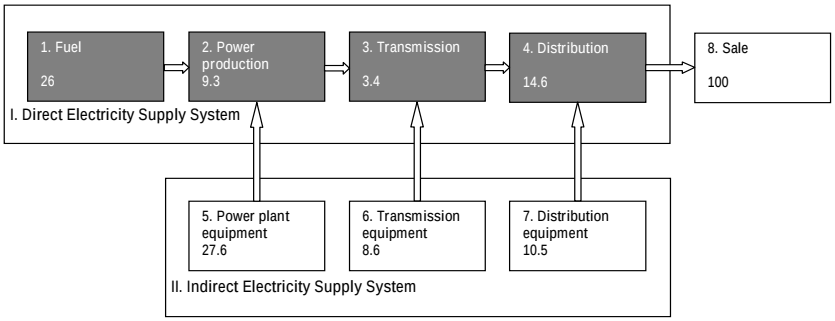

Figure 2. Value added distribution in a coal-fired electricity system[3, 4] [4]

Figure explanation: We have an electricity supply system delivering electricity at the consumer level for 100 value units, for instance, 100 DKK. Looking at I, the Direct Electricity Supply System, it can be seen that out of these 100 DKK, 53.3 DKK is paid to the direct electricity supply system as a whole, with 26 DKK paid for coal, 9.3 DKK paid to the employees the power production stations, 3.4 paid to the employees at the transmission system, and 14.6 paid to the employees of the distributions system.

Kommentar [PCRUM1]:

[JF] The amount of 53.3 should also be included in Figure 8, somewhere, perhaps showing clearly that 1. Fuel, 2. Power Production, 3. Transmission, and 4. Distribution all add up to be 53.3 in IV. Direct electricity supply system. All numbers listed in the text (sums of equipment producers and sums of employees of the distribution system, and even sums of what is paid to the power plant producers, etc.) should be shown in the figure, as well. More suggestions come later in this text.

[3] Source Calculated on the basis of SØ89-112, 10 April 1989 ELSAM, Statistic 1991, DEF, and Statistisk tiårsoversigter 1980-1989. The cost distribution between production and transmission is calculated on the basis of SØ89-112, ELSAM. In this calculation an interest rate of 1% is used, which was the inherent interest rate in the cost structure at that time. With a higher interest rate, the indirect electricity supply system would have a higher proportion of the 100 value added units.

[4] *It is worthwhile to remark that future electricity systems with no fuel use will ceteris paribus have a higher proportion of the value added chain within* direct and indirect *power production, transmission and distribution. Furthermore, it is probable that a higher proportion will be in the* indirect *electricity system.*

So out of 100 DKK**,** 27.3 DKK is paid to the employees in the direct electricity system.

Looking at II, the Indirect Electricity Supply System, 46.7 DKK total is paid to the indirect electricity supply system. Out of these, 27.6 is paid to power plant equipment producers, 8.6 DKK to producers of transmission equipment and 10.5 DKK to producers of distribution network systems.

The value-added chain of energy conservation- renewable energy systems
The present electricity system in Denmark includes wind power production amounting to 15% of the total Danish electricity consumption as well as some development of biomass-based electricity production. Upcoming developments will probably also include the extensive use of photovoltaic and wave energy-based electricity production. Further use of wind-power will require the introduction of regulation facilities synchronising the wind power production with the consumers consumption needs. But what are the typical features of these “new” non-fossil fuel and non-uranium technologies, when described with the same “value-added chain” methodology, as we have used above? Figure 2 deals with this question.

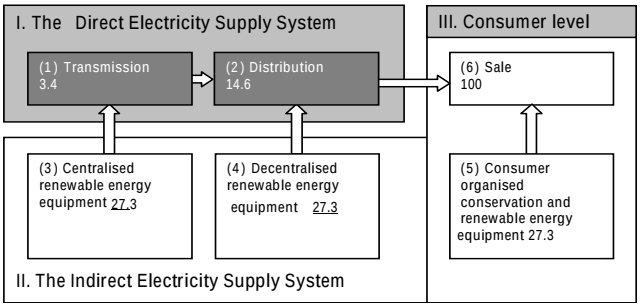

Figure 2. The value-added chain of upcoming renewable energy and conservation systems [4]

***Figure explanation*:** The assumption is that the renewable energy system can produce energy at the same price and with the same transmission and distribution grid as the current network system. A further assumption in this example is that the renewable energy technologies are distributed in such a way that one-third of the indirect electricity supply system will be linked to the central transmission level, one-third to the decentralised distribution level, and one-third to the household level. With these assumptions, the value-added distribution will be as shown in Figure 2.

Figure 1 shows the value-added chain in a typical "sunset" coal/uranium based electricity production system. Figure 2 illustrates a typical "sunrise" renewable energy conservation value-added chain at the energy scene. In the following we will shortly analyse the consequences of establishing a transition between the "sunset" technology value-added chain in Figure 1 and the "sunrise" technology value-added chain in Figure 2.

Technological change and the value-added loss of fossil fuel and uranium based companies
The characteristics of the value-added change from fossil fuel and uranium based to renewable energy systems can be described by combining Figure 1 with Figure 2, as it is done in Figure 3 below.

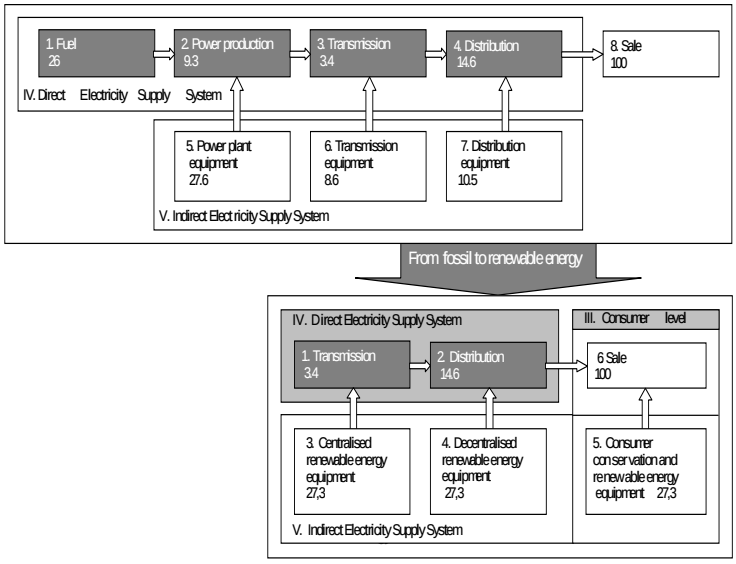

Figure 3. The change in value-added profile connected to the change from uranium and fossil fuel -, to renewable energy and energy conservation systems. [4]

Figure explanation: In the old fossil fuel based system a 100 Dkk sale at consumer level will have the value added divided between the different levels of vertical integration as shown in the upper figure.

The figure at the bottom shows the value-added distribution in an energy conservation and renewable energy system.

From Figure 3 we can observe that the value-added chain of renewable energy and conservation (REC) technologies differs clearly seen in relation to the value-added chain in a fossil fuel based system within two areas:

a. In the REC value-added chain, the fossil fuel value-added part has disappeared, and is replaced by investment in renewable energy capital equipment.
b. In the REC value-added chain, the power production value-added in a specific direct electricity supply system organisation has been replaced by "renewable energy system automation", where it is probable that the maintenance, at least at the decentralised and consumer level, will be performed by the suppliers of the windmills, the photovoltaic cells, the hydrogen production system, the electricity battery charging system, etc. The

need for a specific power production organisation might decrease or disappear, as the day to day work on a power plant has been replaced by automatons requiring maintenance from, for instance, the windmill factory.

It is naturally possible that the existing power company organisations will take over the maintenance of the renewable energy automatons, especially those connected with the large renewable energy plants at sea. But even in this case, the added value directly linked to the power sector will only be halved compared to the present day.

As a consequence of (a) and (b), the direct electricity supply system organisation might therefore decrease its size until it only consists of the transmission organisation and the distribution network organisation.

Consequently, a main characteristic of technological change, as illustrated in Figure 3, can be that the part of the *indirect electricity supply* system which directly relates to equipment for power production. Transmission and distribution might increase from today's 46.7% of the total value added in the fossil fuel system to, in this Figure 3 case, 81 % of the added value in a renewable energy system. This is mainly due to the fact that fuel import is replaced by renewable energy equipment/capital.

An electricity system, like the German one, with its ownership integration of fuel extraction, power production, transmission and distribution ***would decrease in value-added share from 50-60% of the electricity price to around 20%***, if successfully introducing REC energy automatons. This might heavily reduce the profit base of these companies, and reduce the share value considerably.

In an electricity system like the Danish, the value-added decrease would be considerably lower, ***from around 27% to around 18% of the electricity price.***

From the above discussion we can conclude:

a) That due to the different institutional characteristics of at the one hand the uranium and fossil fuel "sunset" technologies, and at the other hand the energy conservation and renewable energy "sunrise" technologies, there is an organisational resistance against "Green innovation" build into the old uranium and fossil fuel companies.
b) That people and organisations linked to the old system are simultaneously losing value-added, since their organisations have no comparative advantage, when dealing with the new technologies, and therefore cannot expect to achieve 100% of the market for energy conservation and renewable energy.
c) That even if we assumed that the old uranium and fossil fuel companies would achieve a 100% market share of the energy conservation and renewable energy technologies, they would lose value-added, as the value-added share in the direct electricity system decreases in the "Green innovation" transformation process.

Large parts of the jobs and profit thus will go to new technological systems with very different value-added profiles and organisational "needs". Consequently the political system should be aware, that a "green innovation" policy would meet systematic resistance from the old uranium and fossil fuel companies.
But how should the political process be designed in order to cope with this resistance. This question is in focus in the next section.

5. Conclusion: Political liberalization and the levels of political and institutional change

In figure 4, the different "battlefields" of technological transformation are illustrated.

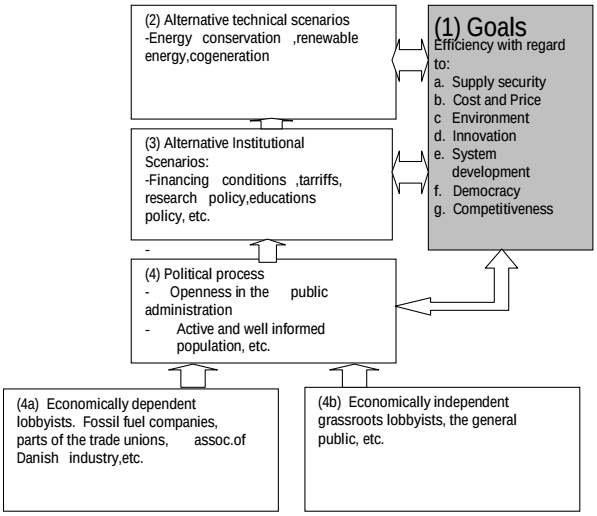

Figure 4. "Green innovation" and political liberalisation

In box (1), goals the discourse regarding the goals and norms is performed.
In box (2), the discourse regarding the realistic technical scenarios is carried through.
In box (3), the discussion regarding concrete institutional reforms is taken.
In box (4), the discussion with regard to design of political institutions is of importance.
In box (4a and 4b) the design of the information and resource balance between lobbyists linked to the old uranium and fossil fuel interests (4a), and the lobbyists which are economic independent from the interests of the uranium and fossil fuel companies.

The concrete Danish development from 1975-2001 has been influenced at each of these levels. Here we will mainly conclude with regard to level 4, the political processes and level 4a and 4b, the information and resource balance between economic dependent and economic independent lobbyists.
From the Danish experience we can conclude, that if the parliamentarians want to have different political scenarios to chose between, they must ***establish a resource and information balance*** between the economic dependent and the economic independent lobbyists. The establishment of this balance is essential, if a successful transformation from uranium and fossil fuel technologies to energy conservation and renewable energy technologies should be fulfilled. The institutions constituting this balance ***can be called the institutions of political liberalisation.***

They are for instance:

- The presence or establishment of *independent research units*, for instance independent Universities, which have the freedom and the resources necessary to be able to design technical scenarios, which are independent of the present central administration and the large energy companies. Such independent universities were present in the Danish development, and made alternative energy scenarios in 1976[5], 1983[6], 1989[7] and 1995[8].
- Extensive *openness of information* both with regard to public plans and the cost and capacity structure of existing energy plants. In Denmark there is a law[5], which requires, that any information between a public organisation and any other organisation is accessible to the public.
- The establishment of independent energy offices[6] and test centres, which can give advises to the public regarding the possibilities and potentials with regard to energy conservation and renewable energy. In Denmark such energy offices and Nordvestjysk Folkecenter for renewable energy[7] got small funds, and has played an important role for the tehnological innovation process.
- Supply public funds to institutions, where the board is independent of the old fossil fuel interests. In Denmark this was done by means of an institution[8], which had means to support a set of pilot plant within renewable energy possible.

The general line in these proposals is, that the Parliament should make sure, that the economic independent groups and the general public is getting free access to information at the energy scene and also sufficient financial resources to be able to develop alternative technical and institutional scenarios. If these "political liberalisation" reforms are introduced and persistently secured, the public and the parliamentarian will get the "freedom of choice" between different technological and organisational scenarios at the energy scene.

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[5] Lov om offentlighed i forvaltningen.

[6] More than twenty energy offices have participated in the development of knowledge and consciousness regarding renewable energy and energy conservation.

[7] Nordvestjysk Folkecenter for Renewable Energy has played an important role for relatively small funds by working with renewable projects at the practical research level.

[8] Teknologirådets styregruppe, which played an important role by distributing funds to renewable energy pilot projects and critical desk research work within the energy area.