Chapter 2

Energy System Analysis: Optimization of the Karlshamn Energy System

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2.1 Executive Summary

The aim of the Energy System Study is to identify cost efficient measures to be taken in the energy system of Karlshamn.

The MODEST model is used to describe the Karlshamn energy system and to optimize the measures to be taken in this systems. The system is optimized for two different cases by considering a) the distributor as the main actor and b) the small and medium customers as the main actors.

The electricity demand for the municipality is divided in five different groups. These include household, small industries, services and two other groups of large industries.

Both existing plants and potential investments are considered in the model. The considered potentials include different kinds of CHP (combined heat and power) plants, hot water boilers, heat pump, efficiency improvements, load management and energy-carrier switching. The assumed cost for the different potentials differs from sector to sector. Restrictions are made on demand-side measures both with respect to their output and costs.

The results of the optimizations are different depending on the choice of the main actor and on input data. With given data, it is generally profitable in both cases to choose load management, energy-carrier switching and efficiency improvements. The profitability of these measures is revealed in more sectors and they are more significant when the customer is considered as the main actor. The total system cost reduction achieved by new measures is very small for case a) compared with case b). The main reasons for this result in both cases are low electricity prices, high investment cost and high restriction on demand-side measures.

The system responds almost in the same manner even at higher rate of electricity price increase. At extremely high real-value increase the whole demand-side measures and some new units would be profitable in almost all sectors.

At lower investment cost for efficiency improving measures with less restrictions the system cost decreases by about 8 % while electricity demand reductions between 10 to 20 % are obtained.

2.2 Introduction

A municipal energy system analysis may consist of different kinds of existing and potential components. The deregulated electricity market, the development of new technologies and environmental restrictions are some of the challenges that must be considered in designing an efficient energy system. In order to be able to design an optimal energy system a well proven method is necessary. Computer simulation models are powerful tools to carry out system analysis with variety degree of complexity. The Karlshamn Energy Efficient System project is about efficient use of energy in Karlshamn. The aim of the Energy System Study is to identify cost efficient measures to be taken in the energy system of Karlshamn. The measures can be taken in both the supply system and on the demand side.
In this study MODEST [4] model is applied to find the optimal structure of the energy system of Karlshamn.

2.3 Methodology

2.3.1 Model

The model used here is MODEST [1,4]. The model can be used to optimize local, regional and national energy systems. Fuel prices, plant efficiencies, demands, investment costs and capacities are some of the inputs that are needed. Linear programming is used to describe relationships between components with in the studied energy system and to optimize its discounted system cost. With the model it is possible to mathematically express different kinds of cases and scenarios. A commercial software is used to solve the optimization problem [2].

2.3.2 Time division

Energy systems in general have dynamic properties that are time dependent. In order to be able to reflect variations of demand, costs, capacities, etc. a reasonable definition of time division is necessary. The selected time division should in general be able to reflect weekly, seasonal and long-term variations of demand, costs, capacities, etc. In this study each year is divided into three seasons, which in turn are divided into diurnal periods (Table 2:1). As it is seen in the table the
winter season contains more diurnal periods (14) compared with the rest of the seasons that have only 4 diurnal periods. The reason for this is that variations of demand and other parameters are more significant during winter periods.

Season	Type of Day		Time of Day	Days of a year	Hours of a year
1 November-March	weekday	1	10 p.m. - 6 a.m.	105	840
		2	6 a.m. - 7 a.m.	105	105
		3	7 a.m. - 8 a.m	105	105
		4	8 a.m. - 12 a.m.	105	420
		5	12 a.m. - 4 p.m.	105	420
		6	4 p.m. - 10 p.m.	105	630
	weekend,holiday	7	10 p.m. - 6 a.m.	41	328
		8	6 a.m. - 10 p.m.	41	656
	peak day	9	10 p.m. - 6 a.m.	5	40
		10	6 a.m. - 7 a.m.	5	5
		11	7 a.m. - 8 a.m	5	5
		12	8 a.m. - 12 a.m.	5	20
		13	12 a.m. - 4 p.m.	5	20
		14	4 p.m. - 10 p.m.	5	30
2 April, september, october	weekday	1	10 p.m. - 6 a.m.	64	512
		2	6 a.m. - 10 p.m.	64	1024
	weekend,holiday	3	10 p.m.- 6 a.m.	27	216
		4	6 a.m. - 10 p.m.	27	432
3 May - August	weekday	1	10 p.m. - 6 a.m.	89	712
		2	6 a.m. - 10 p.m.	89	1424
	weekend,holiday	3	10 p.m. - 6 a.m.	34	272
		4	6 a.m. - 10 p.m.	34	544

Table 2:1. Time Division

2.3.3 Cases

Large consumers like distributors and industries pay less for electricity compared with small consumers. This is one of the reasons why it is necessary to make the analysis from both the distributor and the customer point of view.

Two cases are studied. In the first case the distributor is considered as the main actor and in the second case the customer is considered as the main actor.

2.4 Present conditions

2.4.1 Location and population

The town Karlshamn is one of the five local communities located in the county of Blekinge about 500 km south of Stockholm.

Figure 2:1. County of Blekinge

Karlshamn consists of one city and a few villages, shown on the following map.

Figure 2:2. The municipality of Karlshamn

Main figures about the population and their living are summarized in the following table.

Local Area	Population	Apartments		
		Single family	Multi family	Total
Karlshamn	18 671	3 149	6 076	9 225
Mörrum	3 684	1 220	600	1 820
Svängsta	1 953	965	0	965
Hällaryd	580	287	0	287
Åryd	426	210	0	210
Torarp	271	134	0	134
Pukavik	126	62	0	62
Övr	5 386	2 661	0	2 661
Summa	31 097	8 688	6 676	15 364

Table 2:2. Geographical distribution of population and apartments

2.4.2 Energy Consumption

The public utility in the town is responsible for the supply of about 122 GWh district heating energy annually. The peak load is about 42 MW. About 90 % of the heat needed are purchased from a paper mill plant. Oil-fired boilers produce the rest.

The utility also distributes about 118 GWh electricity annually. A 24 MW peak electricity demand is expected. Minor customers, receiving their electricity by another distributor, consume another 160 GWh per year. Two large foodstuff industries buy a total of 120 GWh electricity annually and a paper-mill, which is the largest industry, has a total electricity demand of about 300 GWh per year. The paper-mill produces almost all its electricity with its combined heat and power plant.
The total energy consumption is summarized in the following table.

Total Estimated Values (GWh/year)				
Category	Electricity	Dist. Heat	Bio Fuel	Oil
Apartm. & Agriculture	124	64	31	85
Services	98	57	0	21
Industrial consumption	472	0	1 705	73
Industrial generation	-266	-106		
El & Heating Services	5	1	0	43
Total "Import"	433	16	1 735	221

Table 2:3. Energy consumption by sector

2.4.3 Time of use and actual Demand

There are two groups of demand in the studied system. The first group is district heating and the second is electricity. The distict heating demand varies from season to season and a large part of the demand depends on the outdoor temprature. The electricity demand is divided in five groups. In these groups only a small part of the demand is temprature dependent.

Season	Type of Day	Time of Day		electricity demand [MW]				
			district-heating	house-hold	industry	services	industry 1	industry 2
1 November-March	weekday	10 p.m. - 6 a.m.	19	13	5	8	12	34
		6 a.m. - 7 a.m.	25	28	7	14	16	36
		7 a.m. - 8 a.m	26	29	8	16	18	36
		8 a.m. - 12 a.m.	25	18	8	19	18	36
		12 a.m. - 4 p.m.	24	19	8	20	18	36
		4 p.m. - 10 p.m.	23	24	6	12	13	34
	weekend,holiday	10 p.m. - 6 a.m.	20	14	5	8	11	34
		6 a.m. - 10 p.m.	23	22	5	10	11	34
	peak day	10 p.m. - 6 a.m.	36	18	6	10	14	36
		6 a.m. - 7 a.m.	43	34	8	16	18	36
		7 a.m. - 8 a.m	46	34	9	18	22	36
		8 a.m. - 12 a.m.	44	23	9	22	21	36
		12 a.m. - 4 p.m.	42	24	9	22	21	36
		4 p.m. - 10 p.m.	42	30	7	15	16	36
2 April,	weekday	10 p.m. - 6 a.m.	12	8	5	7	12	34
september,		6 a.m. - 10 p.m.	15	15	7	17	16	34
october	weekend,holiday	10 p.m.- 6 a.m.	11	8	4	6	10	34
		6 a.m. - 10 p.m.	13	15	5	9	11	34
3 May - August	weekday	10 p.m. - 6 a.m.	6	5	5	6	12	34
		6 a.m. - 10 p.m.	7	11	7	13	16	34
	weekend,holiday	10 p.m. - 6 a.m.	6	5	4	5	10	34
		6 a.m. - 10 p.m.	6	11	4	7	10	34

Table 2:4. Heat and electricity demand by sector

2.4.4 Duration curve for heat and electricity demand

The load duration curve shows the variation of the demand during one year. The curve is created by sorting power values in order of magnitude. The area under the curve represents the total annual energy demand.
The load duration curve for district-heating is shown in figure 2:3.

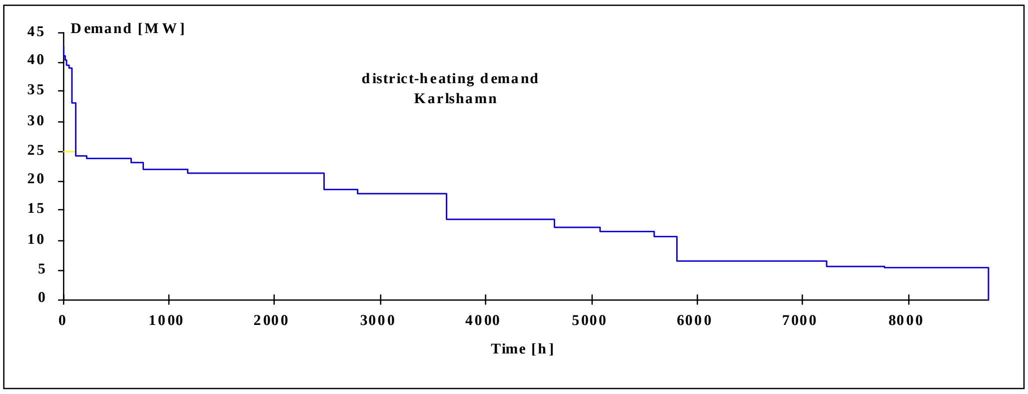

Figure 2:3. Duration curve for the district-heating

The load duration curve for electricity demand is shown in the following two pictures.

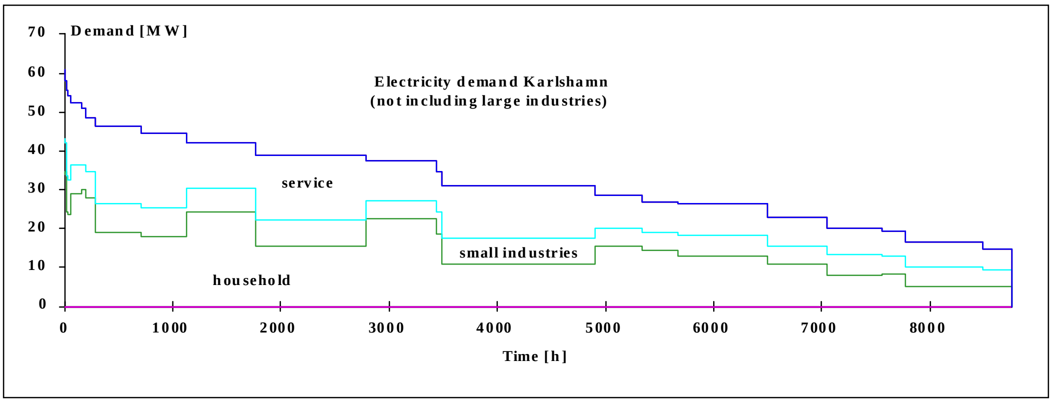

Figure 2:4. Duration curve for the electricity demand by sector

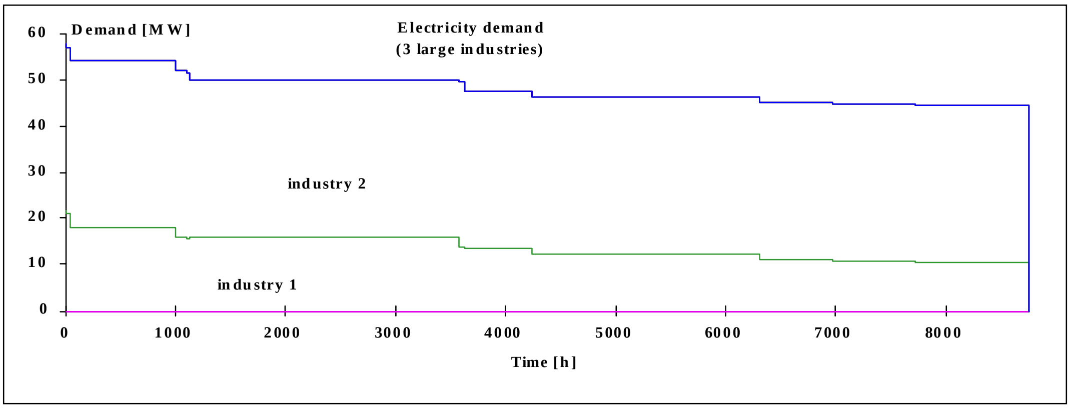

Figure 2:5. Duration curve for electricity demand for large industires

2.5 Energy system under study

The system boundary for the system under study includes the following systems:

1) The public utility with its customer
2) Other regions within the municipality that are supplied by other distributor
3) 2 Food Stuff Industries (industry 1)
4) Paper Mill (industry 2)

The potential investments that are considered in this study are as follows:

- different kinds of combined heat and power (CHP-plant)
- boilers
- wind power
- load management
- efficiency improvements
- energy-carrier switching

All these are schematically described in the following picture.

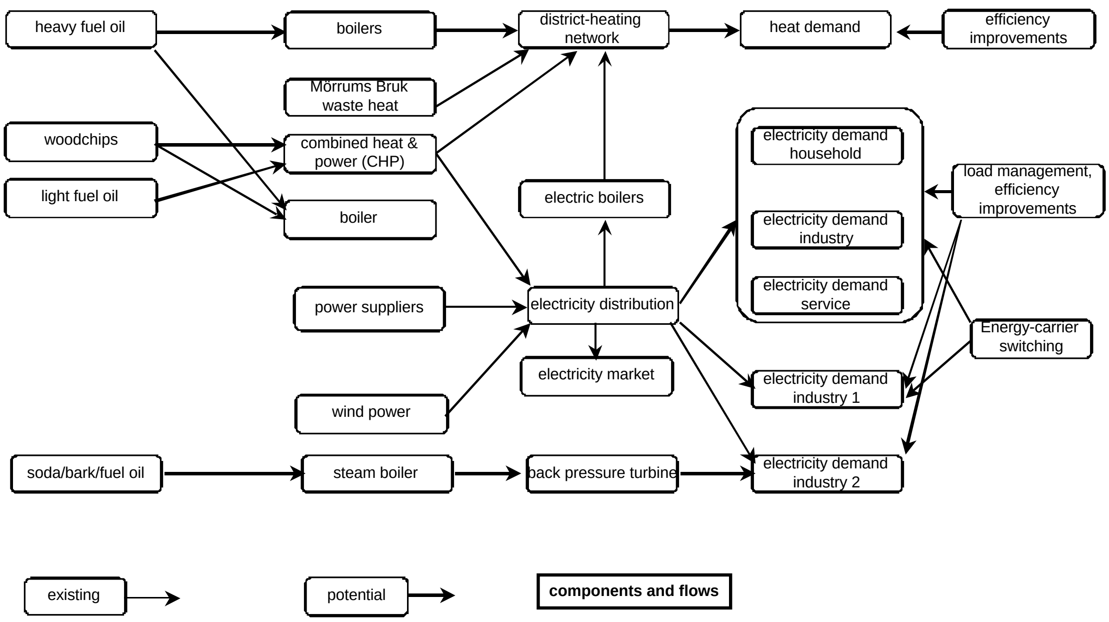

Figure 2:6. Node network of the energysystem in Karlshamn

2.5.1 Investment Cost

The cost for the different measures that are considered in the model are rough estimates. It is assumed that measures like efficiency improvements (conservation) and load management are little cheaper for the industry sector than the household and service sector considered in this study. The table below shows the different types of measures and their corresponding costs.

Type of measure	Life time [Year]	Investment cost [SEK/KW]	Type of measure	Life time [Year]	Investment cost [SEK/KW]
Gas turbine	20	3500	Boiler (fuel oil) (household)	15	3000
Combined Cycle	20	6000	CHP (industry)	10	10000
Steam Cycle	20	20000	Boiler (fuel oil) (industry)	10	1000
Wind power	15	7000	CHP (service)	15	21000
Boiler (bio fuel)	20	3000	Boiler (fuel oil) (service)	15	1500
Boiler (fuel oil)	20	1000	Load management(household)	15	500
Conservation (heat)	25	15000	Load management(industry)	10	100
Heat pump	15	3500	Load management(service)	15	300
Conservation (household)	25	20000	Boiler (bio-fuel) (household)	15	5000
Conservation (industry)	10	13000	Boiler (bio-fuel) (service)	15	3000
Conservation (service)	15	15000	Boiler (bio-fuel)(industry)	10	3000
CHP (household)	15	21000			

Table 2:5. Investment cost of different measures

The demand-side measures that are considered in this study are assumed to have limited sizes. It is difficult to know by how much the energy usage can be reduced in the different sectors. The size of the load that can be transferred from one time period to another is also unknown. In the industry and service sectors, there is no information about the type of heating that is used at present. The maximum allowed sizes for some demand-side measures are shown in table below. The restrictions of this measures are based on previous studies [3].

	maximum allowed size [MW]		
Sector	Load management	Efficiency improvements	Energy-carrier switching
District-heating		3.2	
household	1.6	2.2	5.0
small industries	0.5	0.7	0.3
services	1.3	1.7	0.5
large industries	1.1 - 2.7	1.0 - 2.6	2.0

Table 2:6. Maximum allowed sizes for demand-side measures

2.5.2 Fuel Price estimates

One of the many parameters that have a direct impact on the system cost is the price for fuel. The cost for a given fuel can be different depending on in which sector the fuel is used and what type of fuel it is. The reason for this is the taxation system that is applied in Sweden. Fuel prices that are used in the model for all existing and future plants are listed below.

Type of fuel	Type of user & plant	Price incl. tax SEK /MWh	Type of fuel	Type of user & plant	Price incl. tax SEK /MWh
	Services			**Utility**	
Light fuel oil	CHP	226	Light fuel oil	CHP	200-217
	Boiler	303		Boiler	303
Biomass(woodchips)	Boiler	120	Biomass(woodchips)	Boiler	120
			LP-gas	CHP	186-197
	Household			Boiler	236
Light fuel oil	CHP	270	heavy fuel oil	Boiler	261
	Boiler	343	heat purchase		135
Biomass(briquettes)	Boiler	240			
	Industry				
heavy fuel oil	CHP	119			
	Boiler	127			
Biomass(woodchips)	Boiler	120			

Table 2:7. Fuel prices by sector

2.5.3 Electricity Price estimates

General

Suppliers and big Industries

- Futures price
- Premium for risk and transformation to a load curve
- Administration cost
- HV-network

Medium Industries

- Supplier price + MV-network + administration

Small Customers

- Supplier price + taxes + LV-network + administration

Electricity Prices Estimates for Suppliers and big Industries

The prices for suppliers and big Industries are estimated to increase with 2,5%/year up to a maximum level of about 250 SEK/MWh (annual average). This level depends on the LRMC for new power stations on the European continent. LRMC for natural gas fired combined cycle power stations will be about 200 SEK/MWh. To this should be added the transmission cost from Germany or Poland to Sweden, which will be around 50 SEK/MWh.

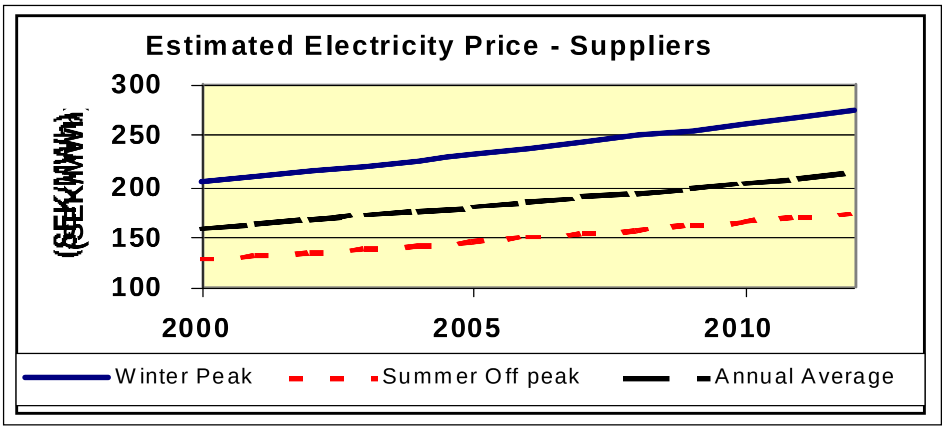

Figure 2:7. Estimated electricity price

Electricity Prices for medium Industries

Supplier price increased by:		
variable network tariff	20	SEK/MWh
administration cost	5	SEK/MWh
Total increase	25	SEK/MWh
Demand charge	408	SEK/kW

Electricity Prices for small Customers

Supplier price increased by:		
taxes	151	SEK/MWh
network tariff	190	SEK/MWh
administration cost	20	SEK/MWh
Total	361	SEK/MWh

(25% VAT for private Customers)

In this study the same supplier price is applied to all sectors. If new power plants prove to be profitable the electricity produced might be used to cover the demand within the system or could be sold on market. The following table shows the prices that are assumed for the simulation.

Season	Type of Day	Time of Day	Electricity price [SEK/MWh]	
			buying	selling
1 November-March	weekday	10 p.m. - 6 a.m.	180	175
		6 a.m. - 7 a.m.	205	200
		7 a.m. - 8 a.m	205	200
		8 a.m. - 12 a.m.	205	200
		12 a.m. - 4 p.m.	205	200
		4 p.m. - 10 p.m.	205	200
	weekend,holiday	10 p.m. - 6 a.m.	180	175
		6 a.m. - 10 p.m.	180	175
	peak day	10 p.m. - 6 a.m.	205	200
		6 a.m. - 7 a.m.	205	200
		7 a.m. - 8 a.m	205	200
		8 a.m. - 12 a.m.	205	200
		12 a.m. - 4 p.m.	205	200
		4 p.m. - 10 p.m.	205	200
2 April, september, october	weekday	10 p.m. - 6 a.m.	130	125
		6 a.m. - 10 p.m.	145	140
	weekend,holiday	10 p.m.- 6 a.m.	130	125
		6 a.m. - 10 p.m.	130	125
3 May - August	weekday	10 p.m. - 6 a.m.	130	125
		6 a.m. - 10 p.m.	145	140
	weekend,holiday	10 p.m. - 6 a.m.	130	125
		6 a.m. - 10 p.m.	130	125

Table 2:8. Electricity prices adapted to the time division

2.6 Results

2.6.1 Case 1 - Supplier as the main actor

With assumed energy prices both for purchased heat and electricity, the optimization has shown that the total system cost, calculated as the net present value for a period of 10 years and a real interest rate of 6%, decreases from 1 064 MSEK to 1 053 MSEK. The measures, which contribute to the system cost reduction, are load management in all sectors and energy-carrier switching within small and large industries. No measures were profitable in the paper mill, because of the low costs of fuel for electricity generation. The results of the optimizations are shown below in the form of duration curve for the different sectors.

District heating

The optimization has shown clearly that there will be no need to consider new plants. This is true as far as the price for purchased heat is lower than 150 SEK/ MWh. New plants like biomass-fired boiler and heat pump will be profitable if the price for purchased heat exceeds 200 SEK/MWh.

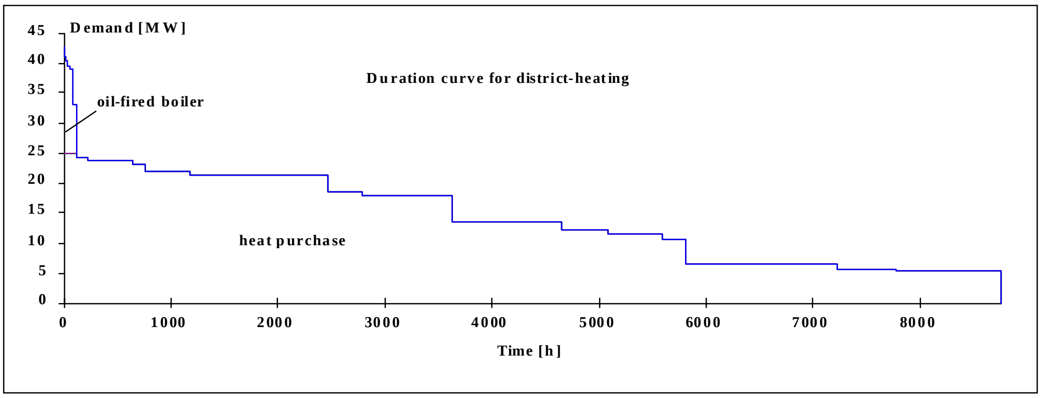

Figure 2:8. Duration curve for heat supply: district heating

The household sector

The electricity demand for this sector is about 125 GWh annually. As far as the supplier is considered as the main actor, no measures except an insignificant load management is profitable here.

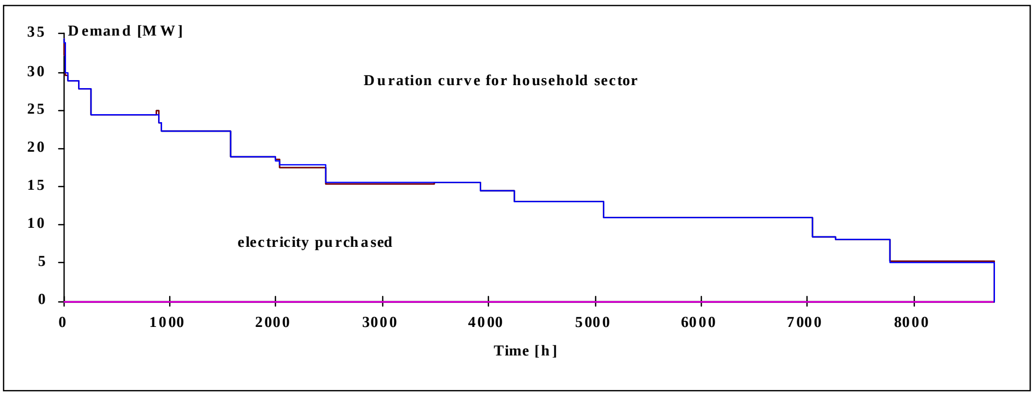

Figure 2:9. Duration curve for electricity supply: household

Small industries

The electricity demand for this sector is about 51 GWh annually. The assumed cost to implement load management and energy-carrier switching for this sector is lower than that of the household sector. Therefore, the optimization shows that these two measures are profitable.

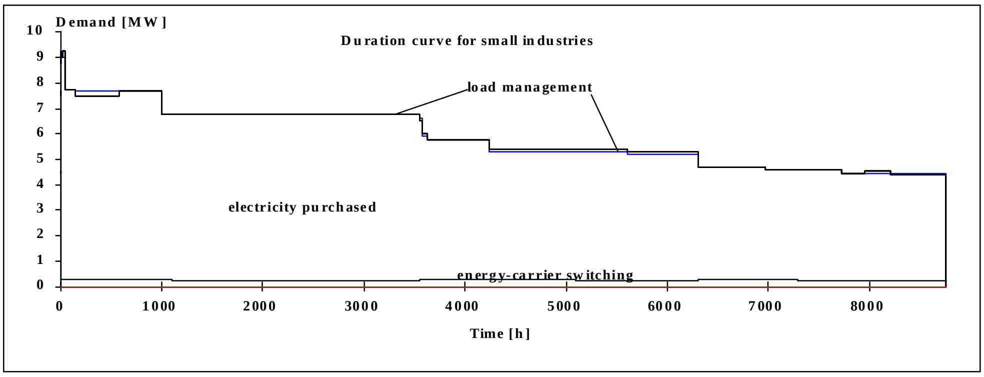

Figure 2:10. Duration curve for electricity supply: small industries

The service sector

The electricity demand for this sector is about 100 GWh annually. From the supplier point of view the service sector is similar to the household sector and therefore similar results are obtained here.

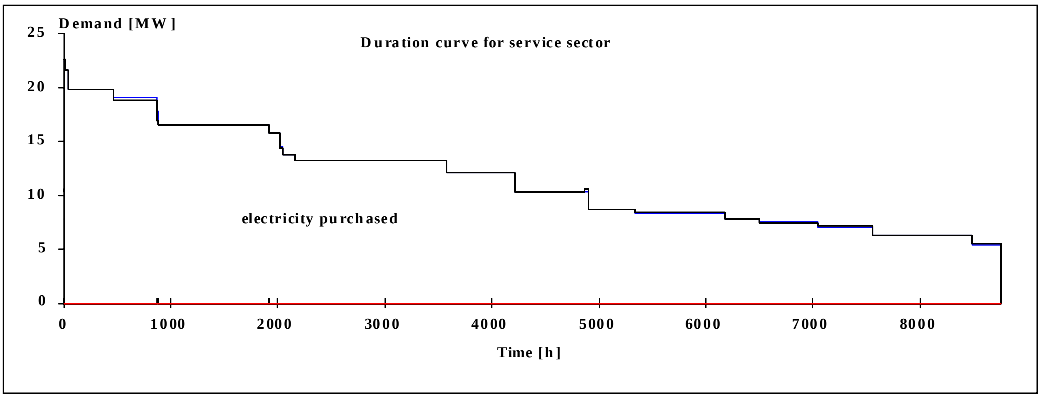

Figure 2:11. Duration curve for electricity supply: service

2.6.2 Case 2 - Customer as the main actor

In this case, energy saving measures will result in that the total system cost for 10 years decreases from 1 568 MSEK to 1 534 MSEK. The measures that contribute to this reduction are load management within small and large industries, efficiency improvements within small industries and services, and energy-carrier switching in all sectors. No measures are needed for the paper mill, because the assumed cost for electricity generation within the plant is very low. The result of the optimization is shown below in the form of duration curve for the different sectors.

The household sector

To consider the customer as the main actor gives a different solution. Customers in this sector pay high price for electricity therefore the measures, small CHP and energy-carrier switching are profitable here. Load management is not attractive here because no demand charge is considered in this case.

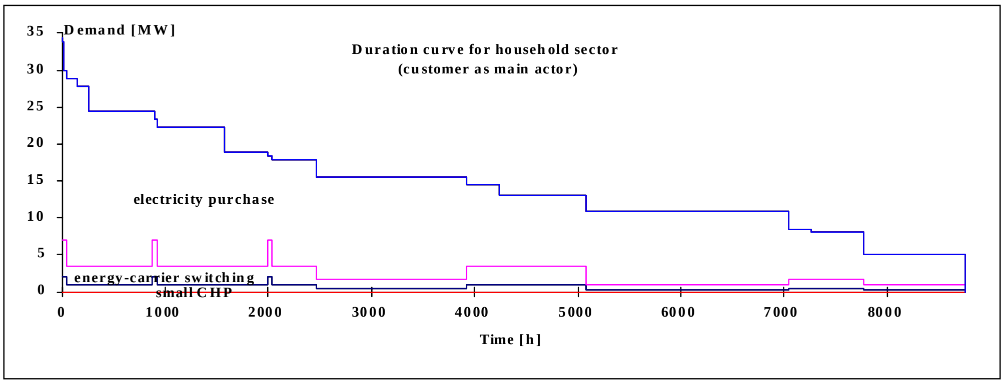

Figure 2:12. Duration curve for electricity supply: household

Small industries

The assumed cost to implement the measures, efficiency improvements, load management and energy-carrier switching are lower for this sector. Therefore, the optimization shows that these three measures are profitable. Very small CHPs are also profitable in this case.

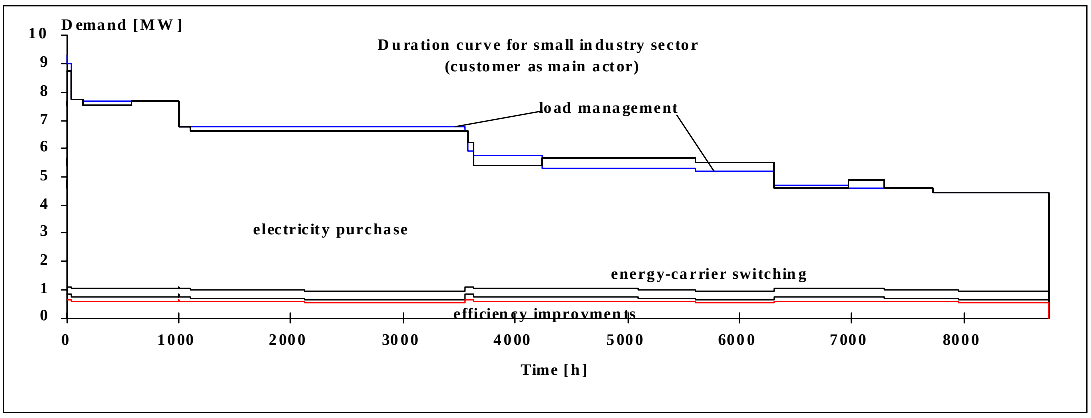

Figure 2:13. Duration curve for electricity supply: small industries

The service sector

The service sector is to some extent similar to the household sector and therefore the results are comparable. Here, efficiency improvements and energy-carrier switching are quite attractive measures that will contribute to reduced electricity demand.

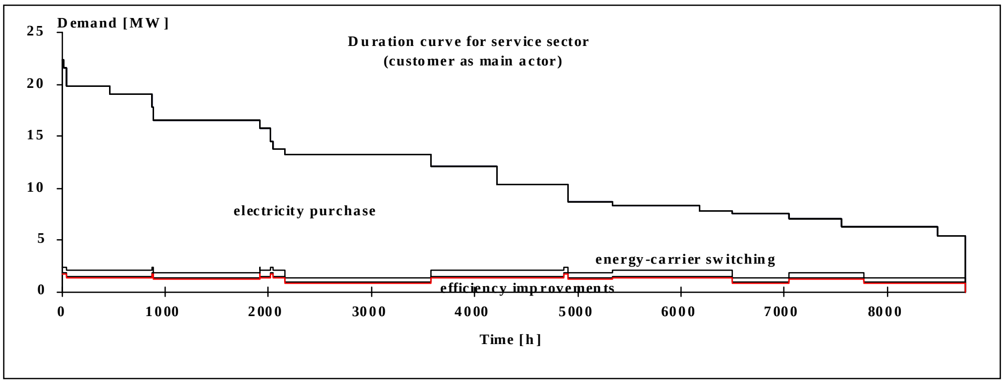

Figure 2:14. Duration curve for electricity supply: service

Large industries

Large industries pay less for electricity compared with the other sectors. This makes it difficult for some measures to be attractive. It might however be profitable to replace a certain amount of electrical energy that is used for heating purposes.

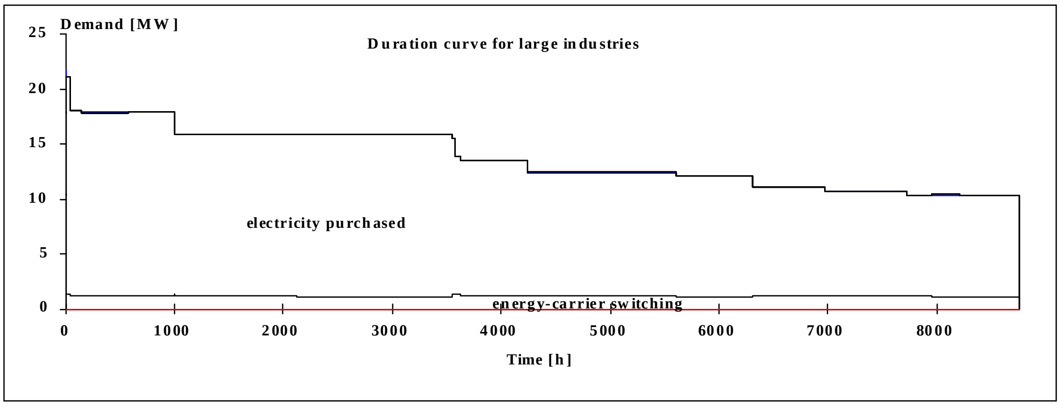

Figure 2:15. Duration curve for electricity supply: large industries

2.7 Sensitivity analysis - Customer as the main actor

2.7.1 Higher rate of electricity price increase

In this sensitivity analysis the system cost is allowed to increase in order to be able to see how the choice of measures changes as the cost changes. The system cost is however the objective function of the optimization problem. It is the main variable that is to be calculated. This cost depends on many limits. In this analysis the change in system cost is achieved by allowing the electricity price to increase annually, while other parameters are held constant. The analysis is carried out for four cases and the result is shown in the table below. As the cost increases, the measures that are profitable tend to cover all sectors. If the system cost is allowed to increase by about 40 % (i.e. an annual electricity price increase by 20 %) then, wind turbines and LPG-fired power plant with an output of 4 MW and 18 MW electricity respectively are profitable. Demand-side measures and new units would make Karlshamn self-sufficient in this particular case.

	Annual electricity price increase [%]				
	2,5	5	10	15	20
System cost [MSEK]					
with out measures	1568	1633	1790	1993	2252
with measures	1534	1588	1708	1844	1996
System cost reduction [%]	2,2	2,8	4,6	7,5	11,4
System cost increase [%]					
with out measures	0	4,1	14,2	27,1	43,6
with measures	0	3,5	11,3	20,2	30,1
Selected measures					
Loadmanagemnt	small industries large industries	small industries services large industries	small industries services large industries	small industries services large industries	households small industries services large industries
Efficiency improvements	small industries services	small industries services	households small industries services large industries	households small industries services large industries	households small industries services large industries
Energy-carrier switching	households small industries services large industries	households small industries services large industries	households small industries services large industries	households small industries services large industries	households small industries services large industries
small CHP	households small industries	households small industries services	households small industries services	households small industries services	households small industries services
Windpower	no	no	yes, (4 MW)	yes, (4 MW)	yes, (4 MW)
Large CHP	no	no	no	no	yes, (18 MW)

Table 2:9. System cost and selected measures at different electricity price increase

2.7.2 Higher degree of efficiency improvements with less cost

In this part of the sensitivity analysis only the impact of increased energy conservation measures is investigated. The electricity price is assumed to increase only by 2.5 % per year. Experience from other energy audit studies has shown that it is possible to achieve substantial energy savings by implementing energy conservation measures [6, 7] . The saving is however different from sector to sector. The measures that lead to efficient energy usage could be rather cheaper if compared with costs that are shown in Table 2:5. So in this case the maximum allowed size for efficiency improving measures are doubled while the cost to implement the measures are cut by half. Table 10 shows input data used for this case.

Sector	maximum allowed size [MW]	investment cost [kr/kW]
District-heating	3.2	7500
household	4.4	10000
small industries	1.4	6500
services	3.4	7500
large industries	2.0 - 5.2	6500

Table 2:10. Allowed sizes for efficiency improving measures and their cost

In this case, energy saving measures will result in that the total system cost for 10 years decreases from 1 568 MSEK to 1 443 MSEK. The measures that contribute to this reduction are load management within small and large industries, efficiency improvements and energy-carrier switching in all sectors. The result clearly shows that efficiency improving measures are the major factor for cost reduction.
The following two pictures show how the total demand of electricity would be met and the contribution of efficiency improving measures toward energy saving for this particular case.

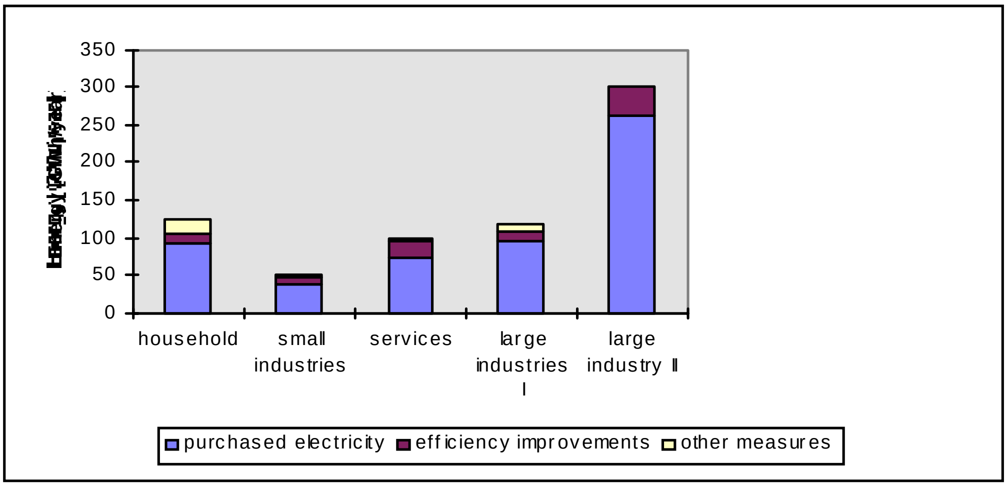

Figure 2:16. Annual electricity supply and demand-side measures

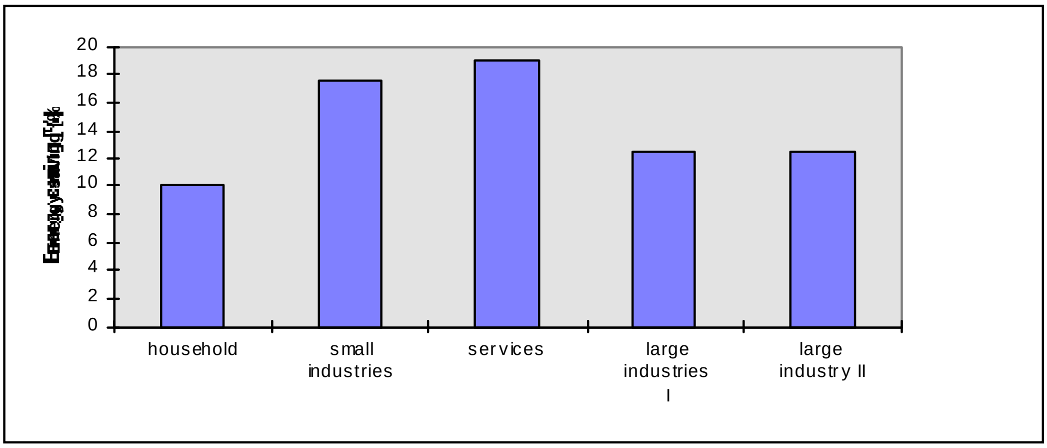

Figure 2:17 Energy savings through efficiency improving measures by sectors

2.8 Conclusions

The results of the optimizations using existing technology, are different depending on the choice of the main actor. The changes in total system cost are rather small in both cases. However the influence of the optimization is bigger when the small customers are treated as the main actors.

With given data and the supplier as main actor it will be profitable with the following measures:

- Load management in all sectors
- Energy carrier switching in small industries

With given data and the customer as main actor it will be profitable with the following measures:

- Load management in small and large industries
- Energy carrier switching in all sectors
- Efficiency improvements in small industries and in the service sector
- Small CHPs in small industries and in the household sector

The main reasons for this result are a combination of cheap electricity and rather expensive energy appliances. Another factor that has affected the result toward this direction is that the measures, load management, energy-carrier switching and efficiency improvements were not allowed to exceed predefined limits.

Sensitivity analysis on the other hand has shown that the profitability of the more likely measures is just a question of cost. If additional costs can be covered by some means, measures like load management, efficiency improvements, energy carrier switching, small and large CHPs and wind turbines would lead to a self sufficient and efficient energy system in Karlshamn. Only efficiency improving measures could cut the energy demand by up to 20 % depending on the type of the sector.

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