Energy Efficient Communities –

First results from an IEA Collaboration Project

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Summary

The background and purpose of a project to evaluate international experiences on planning and implementation of “Energy Efficient Communities” is explained. First results of two German Case Studies are presented, showing approaches and successes/failures on different levels of “communities”, and conclusions to be drawn for other cases.

Keywords: Urban energy planning, community energy assessments, energy system models

1. Introduction

The long-term target of GHG-reduction (minus 80 % for industrialized countries until 2050) will include all major domains of energy use – energy supply, transportation, industry and the building sector. Since over 40 % of the end energy use is caused by the built environment, an increase of the energy performance in this sector, together with the increased use of renewables, will be the key to a successful energy and climate change policy in the industrialized world.

80 % of the built environment is located in towns and cities. For this reason, it is decisive that cities, small or large, will be able to achieve very ambitious energy goals, and this will entail enormous changes in urban fabric and urban energy use patterns, which so far are not obvious to many.

During recent years, big technical progress has been made concerning the energy efficiency of new buildings in the residential and commercial sectors. New energy standards like the German “Passivhaus” or the Swiss “Minergie”, or even “Net Zero Buildings”, have been introduced successfully, which have enabled a reduction of end energy consumption by a factor of 4 - 5 compared to new buildings built according to the building standards of the 90ies. Is this already the solution of the problem? Looking at the development of the energy or GHG balances of cities, the general answer must be “no”. Irrespective of the fact that such balances are hardly ever made, a reduction of the energy consumption of whole cities can rarely ever be observed. In theory, however, it should be easier for neighbourhoods or municipal sub-districts to improve the GHG balance than for individual buildings, because in general there are more technically and economically feasible options on this level.

Obviously, there are powerful barriers that prevent cities from recognizing and implementing their potentials. A strategy to bypass these barriers is needed, in the form of integrated energy planning for neighbourhoods or energy master plans for whole cities. This has been recognized by several countries, where national support programs for urban energy planning projects have been installed.

To use experiences made by those national Case Studies, an international project was commenced within the framework of the International Energy Agency and carried out by the "Energy Conservation in Buildings and Communities" Implementing Agreement. The title of this IEA project, called "Annex 51", is *"Guidelines and Case Studies for Energy Efficient Communities"* (www.ecbcs.org).

2. Annex 51: "Guidelines and Case Studies for Energy Efficient Communities"

Contrary to individual pilot or demonstration buildings, the aim of community-scale energy concepts must be to find an economically optimized solution for the whole planning area that is considered rather than introducing cutting-edge technical innovations for several individual buildings, otherwise comprehensive implementation would not be achievable. This makes a big difference between projects that involve just a few (pilot or demo) buildings and community projects: differences in targeting, planning methods and implementation strategies.

In order to accelerate such community scale projects, some countries have launched specific programs for community projects, with notations like Eco City, Víllе Durable, Carbon Neutral Communities etc. The experiences and lessons learned by such Case Studies shall be evaluated within Annex 51 with regard to concept definition, assessment indicators, planning methods and implementation strategies – and, in particular, with regard to lessons learned by these Case Studies to be transferred to other community scale projects.

The term "communities" does not define a specific kind of settlement, such as a neighbourhood, building zone, quarter, sub-district, town etc. With regard to urban energy planning, the *lower end* in the size of "communities" that are to be addressed by urban energy planning is given by the "system aspect": as soon as the consideration of an ensemble of buildings allows for additional options that are not feasible for individual buildings, it may be considered as a "community system" in the context of energy planning.

Comprehensive long-term energy strategies for *whole towns or cities* are equally important as energy planning for neighbourhoods, settlements or city districts. The evaluation of methods to develop urban energy (or climate change) master plans and suitable implementation strategies for urban administrations is therefore included into the scope of Annex 51. Consequently, Case Studies both for neighbourhoods/districts and for whole towns/cities will be carried out. One result of the Case Study evaluation will be a "Guidebook to Succesful Urban Energy Planning". In addition, a planning tool for decision makers in the pre-design phase of a community project, called "District Energy Concept Adviser" will be developed.

The project has been started in spring 2009 and will be finished until autumn 2012. 11 IEA member countries participate in Annex 51.

3. Two Case Study Examples

More than 20 Case Studies, both on neighbourhood and on city scale, will be evaluated during the work of Annex 51. These Case Studies are in a different status of work. This paper is presenting the results of two German Case Studies, which were among the cases that have been evaluated first.

3.1 Future-proof development concept for the Karlsruhe-Rintheim residential sub-district

This neighbourhood, located in the City of Karlsruhe, consists of 40 multi-family buildings of 40 - 55 years age, with 1 300 flats and ca. 2 500 inhabitants, 2 schools and few retail businesses. There is an urgent need for improvement of the whole neighbourhood to avoid continuous future deterioration.

The aim of the project is (1) to find an economically viable retrofit concept for all buildings including their energy supply, using local sources and (2) to establish a general neighbourhood development plan to ensure future attractiveness for inhabitants and investors. The project is in its implementation phase, which will be completed until 2014. About 50 Mio. € are to be invested by several stakeholders to implement the concept. The work for planning and, in addition, the energy conservation investments to refurbish two existing building of 30 flats each using LowEx-Technologies is financially supported by the State Secretary of Economics, Berlin. Within the framework of the project, an extensive measurement program is pursued over 3 years to track the performance of individual measures.

3.1.1 General approach

Fig. 1 shows a model of the neighbourhood, consisting of 4 and 5 storey multi-family buildings in the northern part, constructed 1954-1955 and containing about 30 flats per building, and multi-storey residential buildings (up to 17 storeys) in the centre of the neighbourhood, constructed 1970-1974. The empty space below is the remainder of 4 demolished buildings where new residential or student dormitory buildings (100 - 150 flats) are planned. 2 elementary schools can be seen at the bottom of the model. 90 % of the residential buildings are owned by one housing company, Volkswohnung Karlsruhe, which is owned by the municipality.

Fig. 1 Karlsruhe-Rintheim: a model view

The older buildings had originally been equipped with coal stoves, which later were replaced by natural gas heaters and decentralized gas or electric hot water boilers in the bathrooms. The younger buildings have gas heating centrals with central DHW supply.

In 2003, a refurbishment program was initiated by Volkswohnung, which aimed at a stepwise modernisation of the whole building stock including energy retrofitting and renewal of the technical equipments.

In 2008, when 9 of the 36 residential buildings had been modernized, talks of the local energy supplier with a refinery, situated on the Rhine river near Karlsruhe, resulted into a decision to use the refinery's large waste heat capacity to supply the base load of the city district heating system (400 MW_{th} peak load). To make full use of the available waste heat, the utility will extend its municipal district heating system and offered to connect also the Rintheim neighbourhood. For this reason, the modernization of the neighbourhood hat to be speeded up to enable a quick connection of the renovated buildings to a new secondary low-temperature district heating system to be installed.

Using this opportunity, a decision was taken by Volkswohnung to develop a sustainability plan for the whole neighbourhood to improve its attractiveness for the residents and to ensure at the same time the long-term return of the large refurbishment investments. This sustainability plan ought to cover not only the modernization of the buildings, but also a customer oriented re-design of the flats, serving the demands of aged tenants and young families as well, a development plan of the spaces between the buildings to offer attractive outdoor quality for the residents and for children, improved commercial and medical services and a traffic/parking plan. With regard to energy supply, an economic optimum of primary energy conservation and CO_2-mitigation should be achieved, using an integrated life-cycle approach.

Since Volkswohnung's tenants belong to the low-income segment, it was important to find a technical concept that would allow for a limitation of rent increases and in the same time a decrease in energy costs which would compensate for much of the rent increase. This is a typical optimization task, that must comprehend conservation and supply measures. For that purpose, an optimization model for building retrofit was developed first, based on the experiences made with the first 9 buildings.

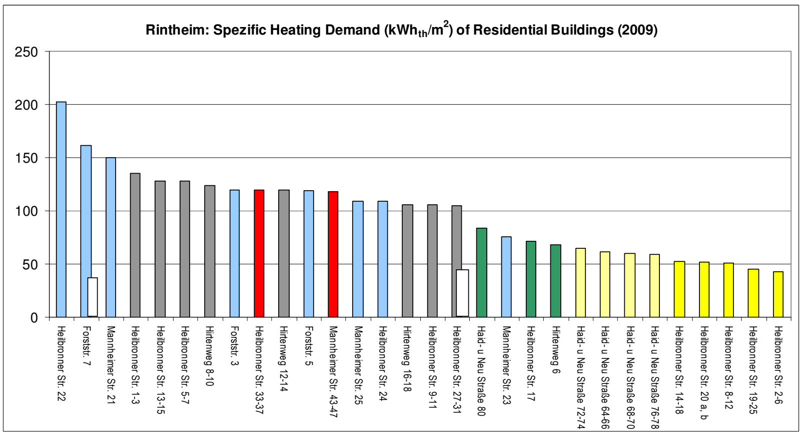

Fig. 2 Measured annual heating demand (2008) of residential buildings in Rintheim (the labels below the bars indicate the buildings addresses)

Fig. 2 shows the distribution of the specific heating demand for refurbished and not refurbished buildings in the Rintheim residential sub-district, as measured in the heating period of 2008 (G^{20}_{15} = 3.200 Kd). The yellow bars to the right of the chart represent refurbished buildings, with an average heating demand of about 50 kWh/m^2, which is 60 % less than the average heating demand of the other buildings (left) not yet retrofitted.

With regard to the remaining buildings and the new option of district heating, the question of an economic energy retrofit optimum was raised. This optimum can be evaluated in terms of "energy saving costs", defined as the ratio of annualized investment costs and energy saved (Ct/kWh).

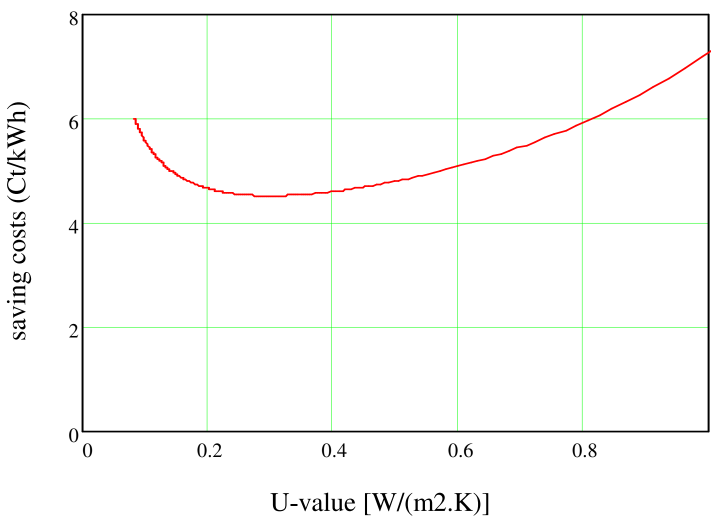

Fig. 3 Energy saving costs by wall insulation as a function of the achieved U-value

For example, considering retrofitting the building wall, these costs depend on the insulation thickness and, correspondingly, on the U-value achieved. Fig. 3 illustrates an example (thermal conductivity λ = 0,035 W/(M.K)), showing that the cost minimum is achieved at U = 0,30 W/(m^2.K), which corresponds to a thickness of 10 cm. However, even a U-value of 0,09 W/(m^2.K), with an insulation thickness of 35 cm, would have lower saving costs than the actual energy price of 6,5 Ct/kWh.

For a comprehensive retrofit concept, there are many different energy conservation options for every building, and it is not at all simple to find that combination that will allow for the least total cost. For that reason, a model was developed by Volkswohnung that - using the cost structure and energy benefits of every measure - is capable to evaluate the least cost combination of energy retrofit measures for every residential building in Rintheim, including envelope insulation, windows replacement, ventilation heat recovery, solar collectors and so on.

Fig. 4 illustrates one result of a model run. The straight rising line left of the total cost minimum results from windows replacement, showing that this is not part of the least cost combination. However, windows of more than 20 years age need to be replaced anyway. Therefore, the model's least cost combination including windows replacement results into an end energy demand for heating of about 50 kWh/m^2. Left from this, the total costs increase steeply. For the building modelled by this run, an insulation thickness of 13, 11 and 23 cm for wall, basement ceiling and attic represented the economic optimum.

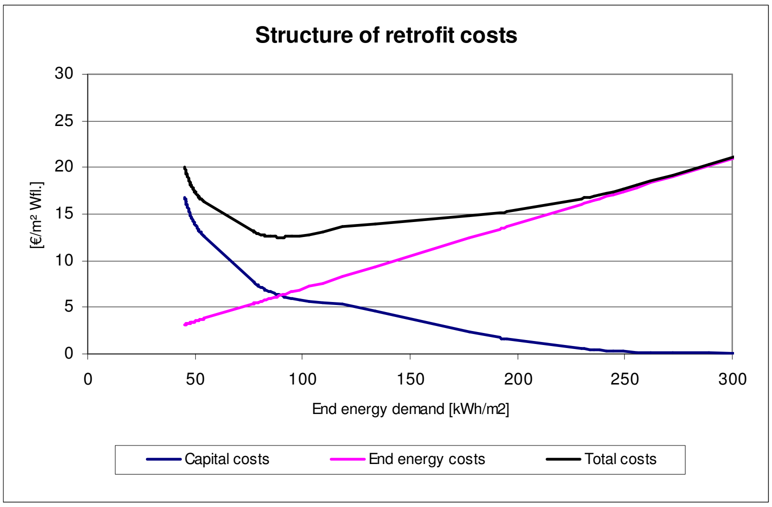

Fig. 4 Retrofit cost curve for a multi family building in Rintheim as a function of conservation standard (kWh/m^2)

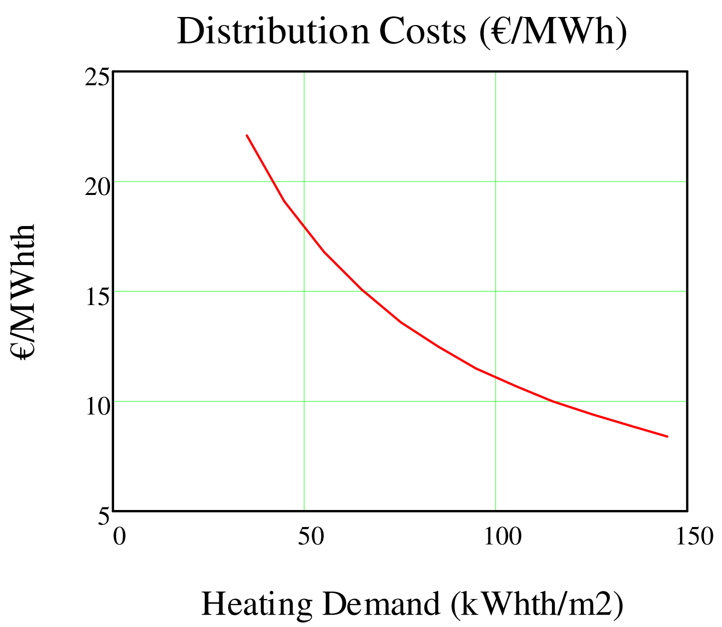

Fig. 5 Distribution costs of district heating supply in Rintheim as a function of the average retrofit standard (kWh/m^2)

However, reducing heating demand by improving the retrofit standard means rising specific costs for district heat distribution (€/MWh_{th}). Is there any trade-off between retrofit and district heating costs? There is no general answer to this question, since it will depend on the building density in the district heating supply area. For the case of Rintheim, this cost dependency was determined in an iterative manner. The result of this calculation - keeping the DHW demand at a constant value of 25 kWh/m^2 - is illustrated by Fig. 5

As a result, the costs of district heating after retrofitting all buildings in Rintheim, acieving an average heating demand of 50 kWh/m^2, will be about 18 €/MWhth (compared to 9 €/MWh without building retrofit), since the grid investments will not change significantly by that. However, compared to the local gas prize the district heat *whole sale price* from the local utility is about 20 €/MWh lower. So, the total *end use price* of district heat in Rintheim will be – at present prize structures – at the same level than end use as prizes (gas was used in most of the buildings before initializing this project).

Fig. 4 shows, that considering energy conservation investments only, the total costs for the tenants after retrofit and connection to the district heating system will not be very much different as before, since the necessary rent increase is compensated by the decrease in energy costs.

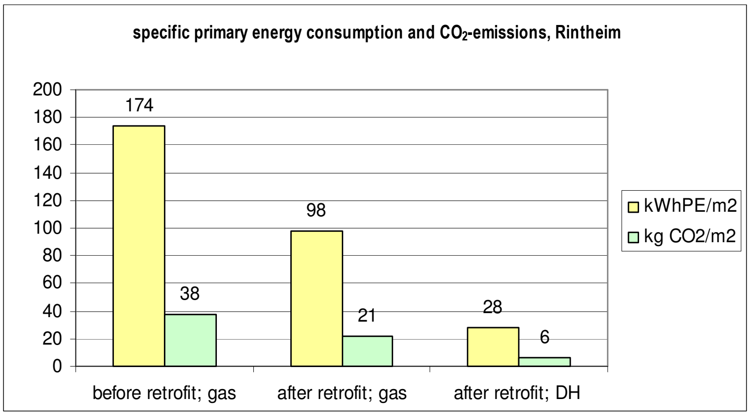

Fig. 6 Characteristic energy consumption and CO_2-emissions before and after retrofit program

The *primary energy consumption* caused by heating and DHW in Rintheim is influenced in a two-fold way: by conservation measures for buildings and by very energy efficient district heating supply using waste heat and cogeneration processes. A detailed energy balance calculation including pumping energy and heat losses of the grid results in a heat supply primary energy factor of 0,39 kWh_{PE}/kWh_{th}. The combined effect including building energy retrofit results into a total primary energy conservation of 80 %!

3.1.2 Energy performance numbers of neighbourhoods

The calculation made to generate fig. 6 can be generalized as a method to derive an energy performance indicator for neighbourhoods or quarters. Is it possible to describe an energy efficient neighbourhood by a characteristic number? Three factors are relevant for that purpose:

(1) low energy demand for heating (and cooling)
→ measure: q_H … annual heating demand q_H (kWh/m^2)

(2) good performance of the energy transformation and supply system
→ measure: e_E … ratio of end energy used to usable energy provided (kWh_{EE}/kWh_{th})

(3) high "quality" of primary energy utilized
→ measure: f_{ren} … fraction of renewables in end energy used (kWh_{ren}/kWh_{EE})

Evaluating the term

$$e_{foss} := \left(q_H + q_W\right) \cdot e_E \cdot \left(1 - f_{ren}\right) \qquad (1)$$

with q_W being the DHW demand and e_{foss} the specific demand of fossil energy of the neighbourhood, one yields a dimension of [kWh_{foss} per m^2 of usable area]. This is a very practical measure, because on the level of buildings all necessary quantities can easily be calculated or measured. This approach can be extended to encompass cooling and electricity demand. Selecting building types of the area, one can calculate the energy performance figure e_{foss} for every neighbourhood, thus providing an easy energy performance ranking method of different neighbourhoods that can complement more sophisticated ranking systems, such as the British "BREEAM Communities" system, which is focused on sustainability aspects rather than energy aspects. Contrary to BREEAM, e_{foss} can be directly measured or calculated and does not need any more or less arbitrary assumptions.

In the case of Rintheim, e_{foss} is 28 kWh_{foss}/m^2 (Fig. 6). Making the same calculation for a "Passivhaus", the resulting value for e_{foss} will be in the range of 35 to 45 kWh_{foss}/m^2, depending on the concrete energy systems used. As a consequence, the energy performance of the Rintheim residential sub-district is even better than Passivhaus standards, but with much less costs.

3.1.3 Conclusions

This first Case Study that has been evaluated in Annex 51 has shown that if one makes use of the local energy potentials and if it is possible to find the optimized combination of conservation and supply measures, even very ambitious energy targets can be achieved with limited cost effects for the end users – at least in the case of the Rintheim residential sub-district. Other cases may be very different in terms of demand structures, available energy sources and organisational possibilities. There will be no general solution that allows similar approaches for all cases. However, it may well be that in other Case Studies similar end results can be achieved with entirely different measures. This is exactly the aim of Annex 51: to learn, which approach under which circumstances works best and how this can be transferred to similar cases. Regarding the general aims of todays energy and climate change policy, it will be absolutely necessary to explore such optimized pathways, otherwise our energy and GHG targets will not be affordable.

3.2 City Level: Long-term Urban Climate Change Master Plan for the City of Freiburg

3.2.1 Development of a municipal GHG policy

The City of Freiburg (200.000 inhabitants) has perhaps the longest tradition of municipal energy and climate change policy in Germany. This policy had its origin in the anti-nuclear-energy disputes of the 80ies. Four phases can be identified: a period of political dispute, a phase of first quantification of urban potentials and targets, a learning phase and a phase of re-adjustment.

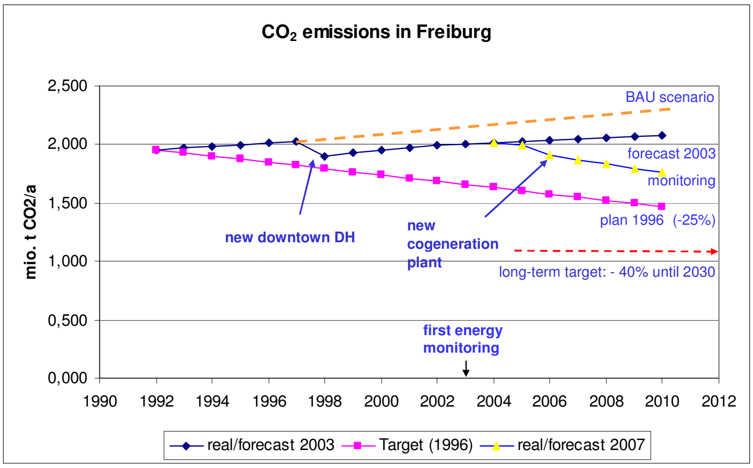

Fig. 7 Projected and real development of CO_2-emissions in Freiburg1992 - 2010

Fig. 7 illustrates the results of these phases in terms of urban GHG emissions in Freiburg, beginning with the first quantification phase in 1995, when Öko-Institute had provided a first assessment of existing potentials and technical options. Based on this, a target of minus 25 % CO_2-emissions until 2010 (compared to 1992) was decided in 1996 by the City Council, while focusing its policy to *solar energy* ("Solarhauptstadt Freiburg") and ambitious standards for *new buildings*.

When a first evaluation of this policy, made in 2003, proved that the target until 2010 would be clearly missed, a new phase of political debate was initiated, accompanied by the analysis of more detailed and realistic energy scenarios and policy instruments. A first conclusion taken was that it would be necessary to track periodically the effects of measures made in the framework of the municipal energy policy. For that purpose, a municipal energy and GHG balancing scheme was developed by IFEU Heidelberg, which is used by the environmental authority since 2006 for bi-annual GHG reports to the City Council. This scheme is now used also by other municipalities and is being improved continuously by IFEU in co-operation with the Statistics Authority of Baden-Württemberg.

A second conclusion that was drawn was that the focus of the GHG policy had to be re-directed to measures that promise to be economically most efficient and therefore would be easier to be implemented. A quick information on potentials and economic viability is provided by "cost/potential curves", as shown by fig. 8. This chart, made in 2003 on the basis of the Öko-Institut assessment and the practical experiences made so far, provides support to policy makers to be able to understand promising fields of action. (Different cities will have quite different such cost/potential curves in general.)

However, developing a successful implementation policy based on such local potentials was a more difficult step, which needed extensive discussions amongst experts, local stakeholders, policy makers and the municipal administration. To enable a detailed discussion of different policies, a model was developed by Öko-Institut, which was used to quantify different assumptions or measures over a given timeline. Based on this, four “scenarios” were defined, describing different conceptual and implementation strategies and their results in terms of GHG emissions.

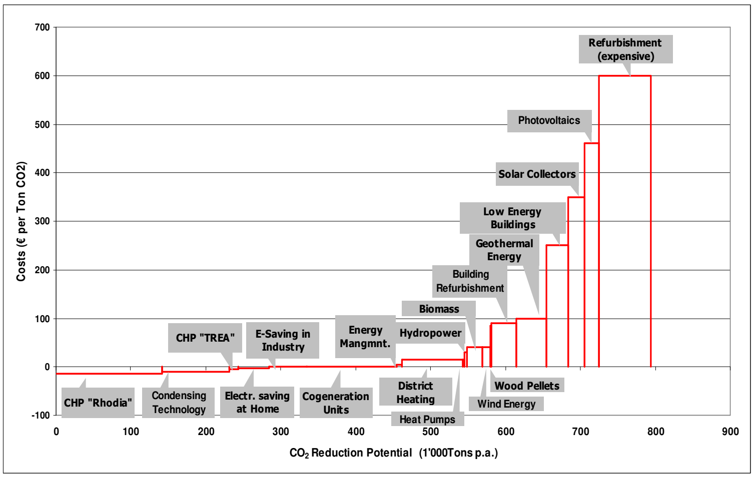

Fig. 8 GHG saving potentials of local measures in the City of Freiburg (t CO_2/a) and assessment of CO_2 mitigation costs (€/t CO_2), Freiburg 2003

As a result of 2 years of discussion, in 2008 an almost unanimous decision was taken by the City Council to define a new GHG target of minus 40 % until 2030 compared to 1992. This decision was combined with a “climate change roadmap”, contending 12 points of action and the obligation of the administration to report periodically on their implementation.

Most important points of the “roadmap” were the support of a retrofit program of the building stock making use of federal building modernisation programs, enforcement of neighbourhood scale district heating schemes using cogeneration, biomass or biogas, substitution of all remaining coal uses, support of electricity saving programs for private households, and a diversity of measures in the mobility sector. Support of solar energy uses should be maintained, because Freiburg wants to continue its image as a “Solar Capital”. Eventually, an ambitious modernization program of the municipal buildings was decided to serve as a model also for other investors in the commercial sector. This policy was to be accompanied by a communication and education program in co-operation with the local trades and industry associations and by a close co-operation with the local utility in terms of energy consultation and the development of new energy services.

3.2.2 Conclusions

The experiences in Freiburg have shown that the pre-requisites of a successful municipal GHG policy will consist of a
- detailed information base on local potentials and options
- realistic target-setting based on achievable results
- detailed delegation of responsibilities and obligations
- continuous monitoring and communication
- project management to be provided by a responsible institution (authority, energy agency, …).

While most of the necessary investments have to be made by third parties, it belongs to the responsibility of the municipality to supply the necessary basics, such as a detailed plan of measures and sub-targets, statistics, monitoring tools, organisational capacities in order to accompany all necessary activities. As can be learned from the experiences in Freiburg, the definition and implementation of a community GHG policy is a task, which requires a certain continuity in know-how and management capacities over many years of time. If successful, it will contribute to local economic development and quality of live.