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Reach a 20% CO_2-reduction at no extra costs with a cost-minimizing investment and dispatch model to cover the combined electricity and heat demand for the region of Vienna

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Overview

Big parts of our today's energy supply systems have grown over time and still contains old facilities. But new technologies using renewable forms of energy are installed step by step and mix up with depreciated assets. In addition to the use of alternative forms of energy, the coupling of electricity and heat supply can make an essential contribution to achieve a cost-efficient and environmentally friendly energy supply as required by an increasing number of national and international policy agreements and respective targets.

In this research we aim at assessing the possibilities to minimize the costs of an existing energy supply structure containing depreciated assets by investing in new technologies and optimal scheduling of all units. This is done using an investment and dispatch optimization model once without restrictions and once with a required 20% CO_2-reduction compared to the actual installed structure. We show that this reduction is achievable at no extra costs.

Methods

A cost minimizing investment and dispatch model based on a mixed integer linear program is developed for this study. In three different scenarios we calculate the costs and CO_2-emissions to cover the yearly heat- and electricity-demand of a region. To represent the demand side one hourly load profile based on final energy data is created for electricity- and one for heat-demand for an entire year. The model offers a detailed representation of the supply side covering all currently installed central plants of a region. This region is partly supplied by a district heating system with fixed size of net infrastructure. The remaining part is provided by decentralized technologies. The decentralized heat-technologies taken into account in this study are: gas boilers, heat pumps and solar collectors. The implemented central heat-technologies are: a power to heat unit, heating plants, heat storage and two different types of combined heat and power (CHP) units (backpressure and extraction units) with three different fuel types (residual waste, biomass and natural gas). Each CHP unit is modeled with individual technological parameters. The objective function is a cost minimization of start-up costs, production costs including emission certificates and efficiency loss, annualized investment costs of additional capacities and costs and surplus of electricity trade.

The "current state" scenario calculates the costs to cover the heat- and electricity-demand with actual installed capacities of all technologies by optimal scheduling of all units. This scenario is further used as reference scenario to which the other scenarios are compared to. In the "optimal system" scenario the model allows investments into every technology except for the written-off CHP units and heat plants. The third scenario calculates the optimal system configuration under the restriction of 20% CO_2-reduction.

Results

The "optimal system" scenario shows that investments into additional capacities of the supply structure can lead to cost savings of more than 5% and a simultaneous CO_2-reduction of about 9% compared to the actual situation. This is mainly achieved in the decentralized part of the system by replacement of gas boilers with heat pumps in combination with an import of the additionally required electricity. In the district heating area, the installation of a power to heat unit results in less operating hours of the CHP units and the heat plants but almost constant emissions and production costs.

The "optimal system with CO_2-reduction" scenario shows that with further change in the supply structure the 20% CO_2-reduction can be achieved without additional costs compared to the actual structure. To reach this reduction an expansion of the renewable energy sources wind and PV has to be done to produce carbon-free electricity. To cover the heat demand a further replacement of gas boilers by heat pumps is required. In this scenario the additional electricity demand for the heat pumps is met by increased production from CHP plants. This means more operation hours and a higher percentage at full-load operation which leads to electricity export instead of import. This is because the CO_2-emission of each Viennese CHP plant is lower than the average emissions of the European electricity generation.

Conclusions

The model results show that the most efficient reduction in total costs and also CO_2-emissions can be achieved by reducing the share of the decentralized technology of gas boilers by heat pumps. The result indicates that every household should install a heat pump for the base load production with a peak-load gas boiler. Although the implemented technology is an air-source heat pump with significant potential even in cities, the combination with a gas boiler will not occur in a relevant share of households due to higher investment costs. The problem here is that investment decisions of single households do not accord to efficient decisions for the overall system. The emission reduction potential within the district heating system is limited because this technology is already efficient. This means that this technology should be developed in areas where it is economically feasible. A solution would be to use comprehensive infrastructure planning for whole regions considering existing technologies and potentials of different supply structures. Based on this planning, political subsidies for efficient decentralized technologies or areas with connection obligations could be developed.