Modelling the Energy Transition in Cities

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Abstract

The history of cities is a history of energy transitions. In the medieval city heating and cooking occurred with wood and peat. The growth of the industrial city in the 19th century was built on coal and electricity. The sprawling metropolis of the 20th century was made possible by oil and gas. How will the city of the 21st century look after the next energy transition from fossil to renewable energy? This paper reports on the extension of an urban land-use transport interaction model to a model of the energy transition in the Ruhr Area, a five-million agglomeration in Germany. The paper presents the planned model extensions and how they are to be integrated into the model and shows first preliminary results.

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1 Introduction

Cities are the largest consumers of energy and emitters of greenhouse gas emissions through heating, air conditioning manufacturing and transport, and by their high density are particularly vulnerable to negative impacts of climate change, such as floods, draughts and heat waves. With a population of more than five million, the Ruhr Area is one of the major urban agglomerations in Europe. How can the ambitious greenhouse gas reduction targets of Federal and state governments be achieved?

Current policy approaches in the Ruhr Area concentrate on incremental measures to reduce energy consumption and greenhouse gas emissions. This is disappointing as the Ruhr, through its industrial past and its polycentric settlement structure, has a particular potential for the reuse of former industrial brownfields and the development of transport-reducing settlement structures.

One reason for the neglect of this potential in the past is the lack of knowledge about the likely impacts of land use and transport policies and other policies to reduce energy consumption and greenhouse gas emissions on land use, mobility and the environment.

This is why the Mercator Foundation, a private foundation located in Essen, Germany, launched a major programme to enhance knowledge and awareness of the need for and challenges of the energy transition in the municipalities of the Ruhr Area. The four-year programme consists of a combination of empirical surveys, research projects, citizen participation and implementation studies.

The project presented in this paper is part of this larger programme. In it a computer simulation model of urban land use, transport and environment developed at the Institute of Spatial Planning of the University of Dortmund will be further developed and applied to assess the impacts of land use, transport and other policies to reduce energy consumption and promote the transition to renewable energy on economy, mobility, quality of life and environment in the Ruhr Area. For this the model will be extended by submodels of renewable energy and energy efficiency of buildings.

The model will be used to simulate scenarios that differ in their assumptions about future energy price increases and possible combinations of measures to reduce fossil energy consumption and to increase energy efficiency and renewable energy use to achieve the energy policy targets of the German Federal Government.

The project is a co-operation between the Wuppertal Institute for Climate, Environment and Energy and the Department of Civil Engineering of the University of Wuppertal and Spiekermann & Wegener Urban and Regional Research, Dortmund (S&W).

2 State of the Art

The history of cities is a history of energy transitions. In the medieval city heating and cooking occurred with wood and peat. The growth of the industrial city in the 19th century was built on coal and electricity. The sprawling metropolis of the 20th century was made possible by oil and gas. How will the city of the 21st century look after the next energy transition from fossil to renewable energy?

The foreseeable impacts of declining energy resources have been a topic of research since the first report to the Club of Rome *The Limits to Growth* (Meadows et al. 1972). Since the 1990s, the intrinsic relationship between fossil energy consumption and climate change had become obvious. Already in 1992, before the United Nations Conference on Environment and Development in Rio de Janeiro in the same year, the German Federal Government established the Scientific Council for Global Environmental Change (WBGU). In the same year the Potsdam Institute for Climate Impact Research (PIK) was founded. With the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change of 2007 (IPCC 2007) a wider public became aware that significant climate changes and their impacts, such as floods, storms or heat waves are no longer avoidable. And it has become obvious that for the mitigation of even worse impacts in developing countries the consumption of fossil energy and the emission of greenhouse gases in the richest countries of the world need to be reduced by 80 per cent.

The term energy transition (*Energiewende* in German) dates back to a book by the German Ökoinstitut calling for the abandonment of nuclear and fossil energy (Krause et al. 1980) and has since been refined and extended to encompass a reorientation of energy policy from centralised to distributed energy generation and energy-saving measures and increased energy efficiency. The energy transition has become an established component of the energy policy of the German Federal government. Its aim is to achieve 50 per cent less primary energy consumption, 50 per cent renewable energy for power and heating and 100 per cent renewable energy for buildings until 2050.

The consequence of this change of awareness has been a growth in scientific attention also for the spatial impacts of energy policy. It has become clear that the ambitious energy policy targets of the German government present a huge challenge not only for national and state planning, such as the alignment of high-voltage power lines and the location of wind parks, but also for local governments to promote energy conservation and increase energy efficiency. This paper focuses on these local aspects of the energy transition.

In response to the growing interest in energy many municipalities developed local energy concepts and invested in energy retrofitting of buildings and centralised heating systems. There are now numerous studies on the impacts of different energy conservation policies, such as the energy transition reports by the German Energy Agency (dena 2010, 2012) and the German Institute of Urban Studies (difu 2012).

However, missing are impact analyses and forecasts which – as far as possible with present knowledge – quantify the likely impacts of the proposed land use and transport and other policies on the reduction of energy consumption and greenhouse gas emissions and the price in terms of necessary investments and losses in consumption and mobility that will have to be paid. Also missing are forecasts of possible indirect impacts, such as positive or negative synergies of different types of policies, such as fiscal, legal or planning policies, i.e. whether policies reinforce, complement, substitute or counteract each other.

Other European countries are more advanced in this respect. One example is the Cities Programme of the Tyndall Centre for Climate Change Research in the United Kingdom (Dawson et al. 2009). Its objective is to develop a model system to simulate the impacts of climate change in cities and compare alternative mitigation and adaptation measures. The model predicts the impacts of mitigation and adaptation measures, such as taxes, fees, emission permits, high-density mixed-used developments, land use restrictions, infrastructure investments, alternative fuels, travel demand management, flood retention basins, heat insulation of buildings and more energy-efficient vehicles in a unified model framework.

3 The Model

The model to be used in the project is the integrated land-use and transport model developed at the Institute of Spatial Planning of the University of Dortmund (Wegener 1982, 2011) and applied in many EU and national projects, such as PROPOLIS (Lautso et al. 2004), Spiekermann and Wegener (2005), STEPs (Fiorello et al. 2006) and Huber et al. (2007).

The model contains submodels of household development, public and private construction, the regional labour and housing markets and a detailed regional transport model. It predicts for each simulation period intraregional location decisions of industry, residential developers and households, the resulting migration and travel patterns, construction activity and land use development and the impacts of public policies of industrial development, housing, public facilities and transport. Figure 1 shows the major subsystems of the model and their main interactions.

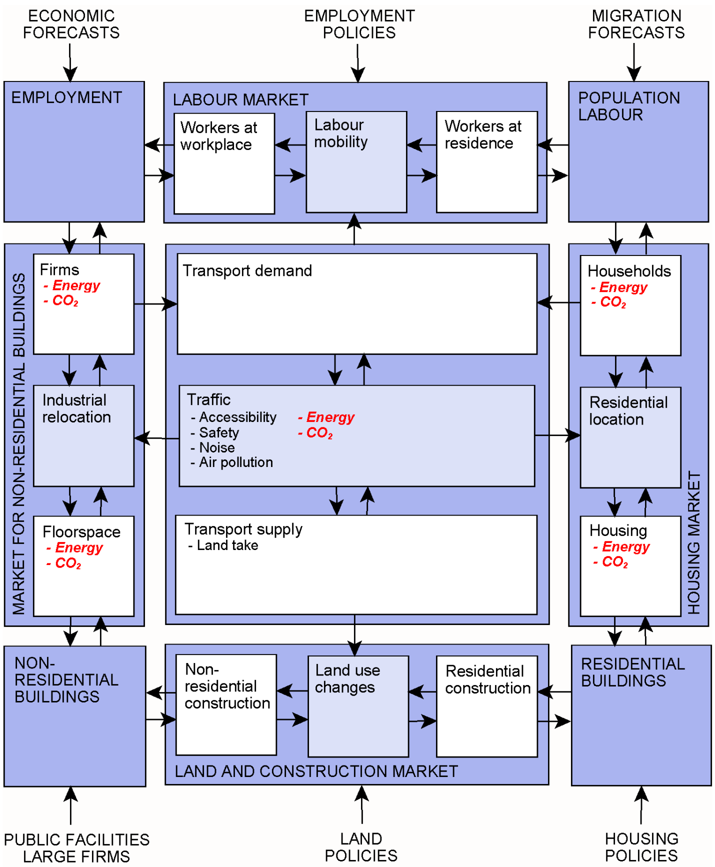

Fig. 1. The IRPUD model

The four square boxes in the corners of the diagram show the major stock variables of the model: population, employment, residential buildings (housing) and non-residential buildings (industrial and commercial workplaces and public facilities). The actors representing these stocks are individuals or households, workers, housing investors and firms:

- the labour market: new jobs and redundancies,
- the market for non-residential buildings: new firms and firm relocations,
- the housing market: in- and outmigration, new households and moves,
- the land and construction market: changes of land use,
- the transport market: trips.

The parts in the model where in the future energy consumption and CO_2 emissions will be calculated are highlighted in red.

For each submarket, the diagram shows supply and demand and the resulting market transactions. Choice in the submarkets is constrained by supply (jobs, vacant housing, vacant land, vacant industrial or commercial floorspace) and guided by attractiveness, which in general terms is an actor-specific aggregate of neighbourhood quality, accessibility and price.

There are six types of exogenous inputs shown on the outside of the diagram: either forecasts of regional employment and population subject to long-term economic and demographic trends or policies in the fields of industrial development, housing, public facilities and transport.

The IRPUD model has a modular structure and consists of six interlinked submodels operating in a recursive fashion on a common spatio-temporal database:

- The *Transport* submodel calculates work, shopping, service, and education trips for four socio-economic groups, and three modes: walking/cycling, public transport and car.
- The *Ageing* submodel computes all changes of the stock variables of the model (employment, population and households/housing) which result from demographic, technological or long-term socio-economic trends.
- The *Public Programmes* submodel processes a large variety of public programmes specified by the model user in the fields of employment, housing, health, welfare, education, recreation and transport.
- The *Private Construction* submodel considers investment and location decisions of private developers, i.e. of enterprises erecting new industrial or commercial buildings, and of residential developers who build flats or houses for sale or rent or for their own use.
- The *Labour Market* submodel models intraregional labour mobility as decisions of workers to change their job in the regional labour market.
- The *Housing Market* submodel simulates intraregional migration decisions of households as search processes in the regional housing market as stochastic microsimulation.

A detailed description of the model is contained in Wegener (2011).

4 Model Extensions

In the project the model will be integrated with high-resolution submodels of environmental impacts of land use and transport so that it predicts not only environmental impacts but also their effects on the location decisions of households and firms (Spiekermann and Wegener 2008). The environmental impact submodels (air quality, traffic noise, biodiversity) are already available but will have to be dynamically linked to the integrated model to make that feedback possible.

Besides the existing submodels of energy consumption and CO_2 emissions of person travel, other energy-related submodels will be developed, in the following order of priority: (i) energy consumption of residential and non-residential buildings, (ii) energy consumption of industrial and commercial processes, (iii) energy consumption of households for appliances and lighting, (iv) renewable energy generation (solar energy, wind energy) and (v) energy consumption of local goods transport.

Only the submodel of energy efficiency of residential buildings is already under development. As energy consumption of buildings is about 40 per cent of total primary energy consumption, improving the energy efficiency of buildings is of central importance. And because the annual rate of new construction is usually less than one per cent of the building stock, this means that without massive retrofitting existing buildings energy policy targets of the German government will not be achieved.

The aim of the submodel under development is to assess the likely impacts of policies to improve the energy efficiency of residential buildings (Fuerst and Wegener 2011). The main problem in this submodel – and probably all submodels dealing with investments in energy efficiency – is not a technical one but to forecast the likely response of private actors, in this case individual house owners or housing corporations, to rising energy prices or financial incentives by government. As long energy prices remain low or rise only moderately, the payback period, i.e. the time until investments in energy efficiency will be returned through energy cost savings, tends to be long, which makes such investments unattractive, in particular for elderly people. Accordingly, in the model investments in energy efficiency of residential building depend on the perceived payback period.

Similar concepts are envisaged for the submodels of energy efficiency of non-residential buildings and energy consumption of firms and households. For the renewable energy submodels accounting models of the existing and used solar energy and wind energy potential will be required. Such models exist as independent GIS-based applications. However, the innovation of this project is to connect them with the submodels of the housing market and the market for non-residential buildings in the integrated modelling framework.

The present study area of the IRPUD model is the urban region of Dortmund in the eastern Ruhr area with a population of 2.3 million. The study area of the beginning project will be the whole Ruhr area, i.e. the territory of the Regional Association Ruhr (RVR) with a population of 5.3 million. Figure 2 shows the present study area, the eastern Ruhr area (the yellow square) and the planned study area, the 53 municipalities of the RVR. A larger area including major parts of North Rhine-Westphalia will be considered as external zones.

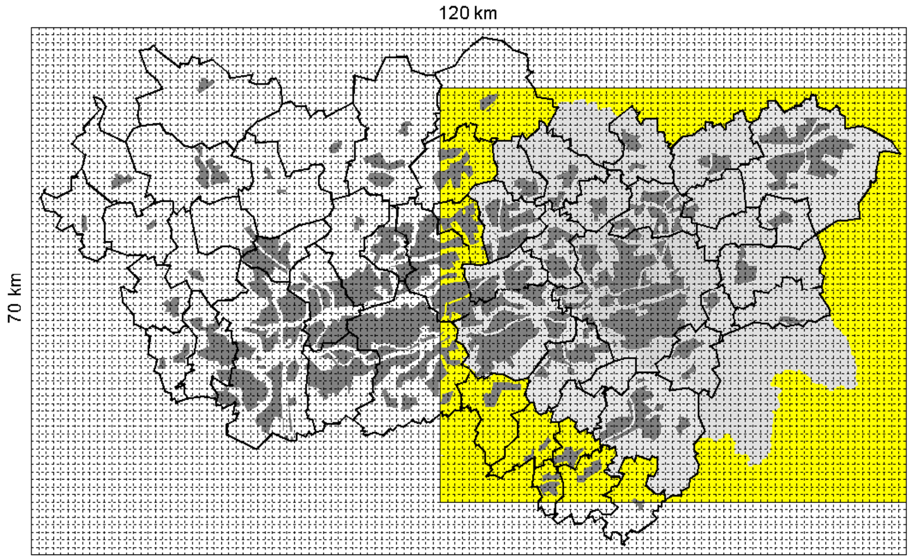

Fig. 2. Study area: the Ruhr Area

For modelling land use and transport the extended study area will be subdivided into about 600 zones and for the environment models into raster cells of 100x100 m size. The extension of the model will require current and historical data about land use, households, residential and non-residential buildings, public education and health facilities and transport networks also for the western part of the Ruhr area. For the environmental submodels data about topography, wind, buildings, land coverage and vegetation will be required.

5 Scenarios

The model system will then be applied to simulate scenarios. The scenarios will differ in their assumptions about future energy price increases and possible combinations of European, national, state and local measures to reduce fossil energy consumption and to increase energy efficiency and renewable energy use. A simulation scenario will be a combination of assumptions about the development of energy prices with one or more policies from the fields of land use planning, infrastructure investment, transport planning and policies to reduce fossil energy consumption, for instance by carbon or fuel taxes or road pricing, and policies to promote the diffusion of renewable energy and to increase energy efficiency.

Target year of the simulations will be the year 2050. The model will produce for each scenario and for each simulation period detailed information about the spatial development of population, work places, land use and buildings, the number of trips by travel time, distance and mode and environmental impacts in terms of energy consumption, greenhouse gas emissions, air quality, traffic noise, open space and biodiversity.

These policy scenarios will be compared with a base or reference scenario in which only the assumed trends will be in effect and no policies will be implemented except continuation of current polices (business as usual). There will be two types of scenarios: *What-if* scenarios answer the question what would be the impacts of policies or combinations of policies (policy packages) on the adoption of renewable energy, energy efficiency and the remaining consumption of fossil energy. *Backcasting* scenarios go beyond this; they answer the question what policies will be required to achieve the energy policy targets of the national and state governments. In both cases possible positive and negative synergies between policies or groups of policies will receive special attention.

The results of the scenarios will be presented in easy to understand visual form and be used to formulate recommendations for policy action.

6 First Results

The project is still in its initial phase so that only very preliminary first results can be presented, and also this would not have been possible if the extended transport network data were not already available from another research project (Reicher et al. 2011). Based on that network data a prototype of the extended transport submodel is already operational.

Figures 3 to 6 on the following pages show first results of that transport model run separately without the land use parts of the model: Figure 3 shows the extended multimodal transport network, Figure 4 shows the result of the travel simulation, flows of more than 200 trips per day by car, public transport and walk and cycle, Figure 5 shows the resulting multimodal accessibility of work places in the Ruhr Area reproducing the historically grown linear configuration of cities along the medieval trade route, the Hellweg, and Figure 6 shows fuel consumption by cars originating in the different parts of the region.

It can be seen that Figure 5 and Figure 6 are more or less negatives of each other: In the high-density most urbanised central parts of the region car travel and hence car fuel consumption is lowest, whereas in the areas in between, and particular in the outermost peripheral parts of the region the dependence on cars and hence fuel consumption are highest.

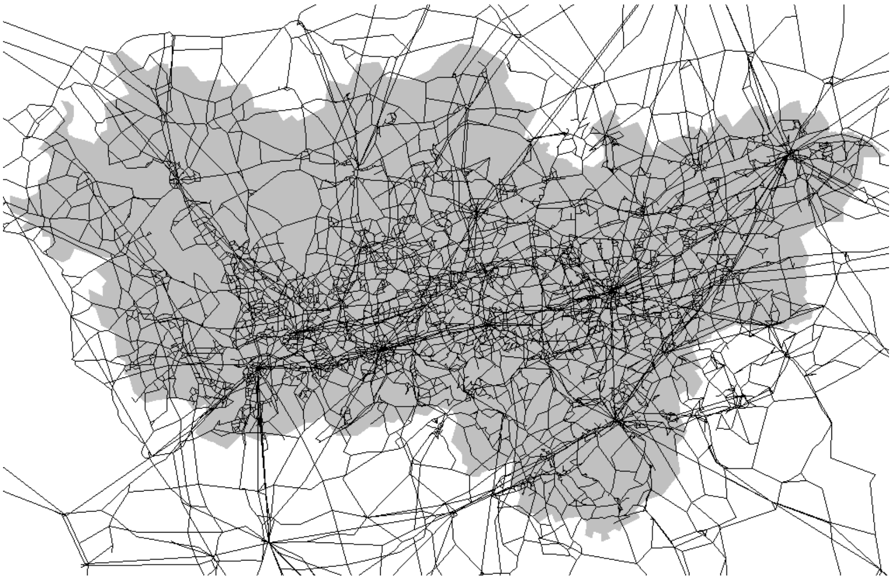

Fig. 3. Multimodal network

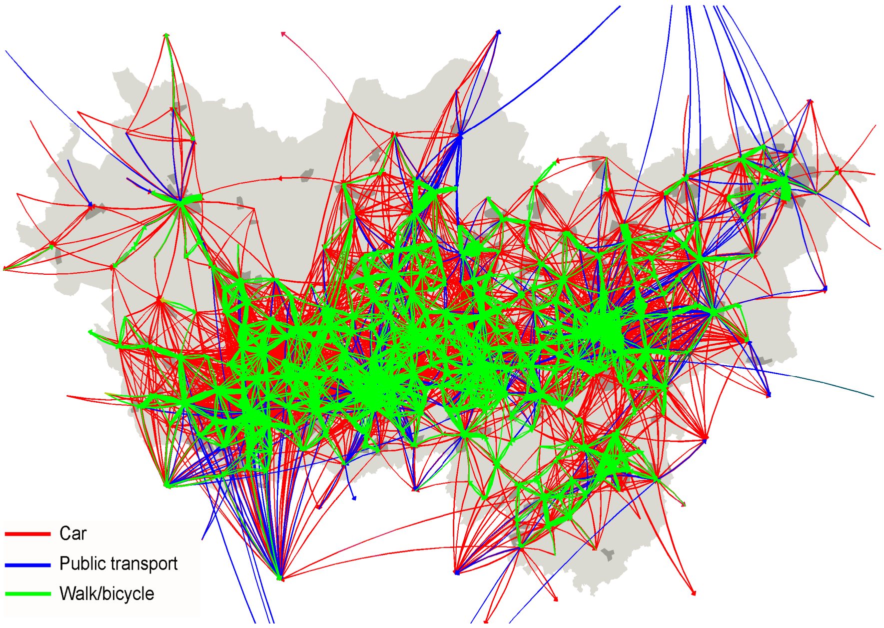

Fig. 4. Trips by mode

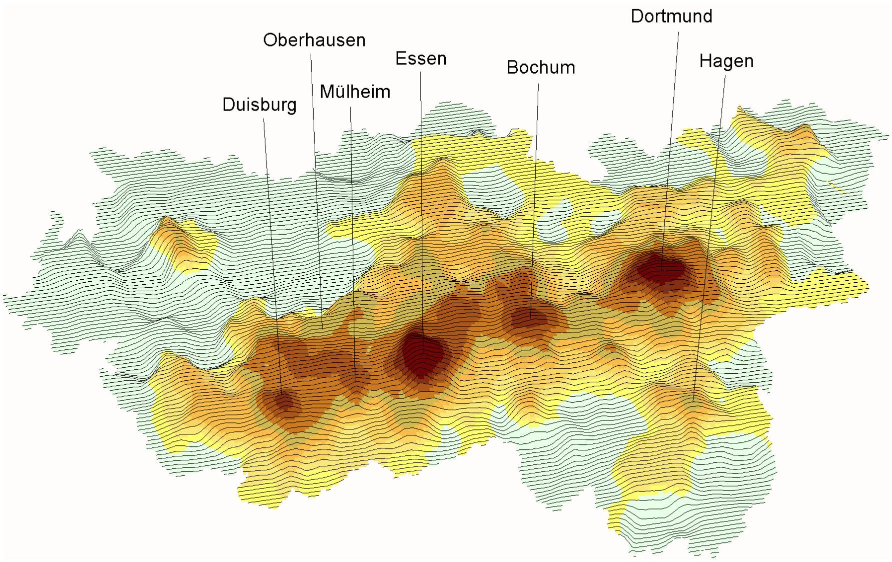

Fig. 5. Accessibility of work places

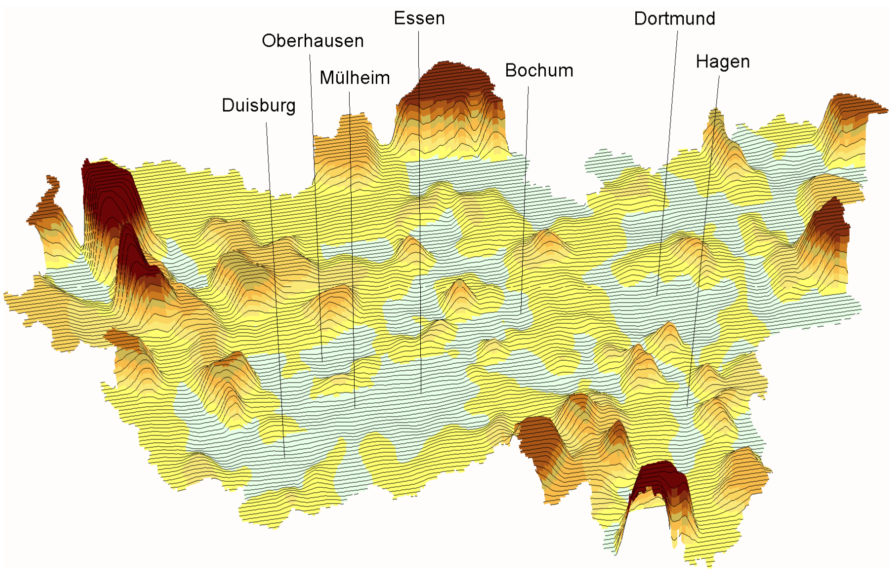

Fig. 6. Car fuel consumption per capita

In the IRPUD model car fuel consumption per capita is a function of number of trips, trip length, modal split, car occupancy and car energy efficiency. Number of trips, trip length and modal split are influenced by the distance of households to destinations, such as work places, shops, schools and leisure facilities, and modal travel cost by each mode to these destinations in relation to household income and travel budgets. Car energy efficiency (fuel consumption per kilometre) is exogenous based on past trends and the diffusion of electric cars.

Accordingly, policies to reduce energy consumption of travel include technological innovation increasing fuel efficiency, transport policies, such as improvement of public transport, pricing to make car travel less attractive, and land use policies to promote higher-density mixed-use settlement structures.

7 Conclusions

Existing urban models have so far assessed the energy consumption and related greenhouse gas emissions only of transport. This paper explored the challenges of extending the scope of urban models to the diffusion of renewable energy and energy efficiency of buildings as important fields of urban energy and climate policy. The paper identified the new submodels necessary for that extension and how they can be interfaced with existing submodels of urban housing markets and markets for non-residential buildings in an integrated urban model and how this is planned to be done in a study for the Ruhr Area agglomeration in Germany.

The conclusion from this analysis is that this field is still in its infancy and that more attempts to extend the scope of urban models in this direction are desirable.

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