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Positive Economic Effects of Energy Efficiency

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Improved Energy Efficiency: Vital for Energy Transition and Stimulus for Economic Growth

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As part of the energy transition process, the German government has set far-reaching energy efficiency targets, including doubling the annual rate of building renovation to upgrade energy performance from one to two percent. DIW Berlin has estimated the additional energy-savings-related investment required to meet these targets and analyzed the impact this could have on the economy. In the long term, the savings on household energy bills far exceed the additional investment. This, combined with further measures to increase energy efficiency in other sectors, substantially reduces energy consumption and greenhouse gas emissions. Even allowing for some elements of uncertainty, these measures to improve energy efficiency have a positive impact on income and domestic demand. They could also result in significantly positive effects on employment, depending on the ratio of productivity gains and new jobs. Nevertheless, the most recent savings are not nearly enough to achieve the German government's energy efficiency targets. Clear and reliable framework conditions are needed soon to increase the number of buildings being renovated to upgrade energy performance. Given the present analyses, which indicate that forcing the pace of energy efficiency improvements has a positive impact on German economic growth and employment, the government's hesitation seems even less justified.

According to the European Energy Efficiency Directive,[1] energy efficiency is defined as the ratio of output of services and goods to input of energy. From a macroeconomic perspective, the aim of an increase in energy efficiency is to achieve a higher contribution to wealth per unit of energy used. Indicators of an increase in energy efficiency are a rise in energy productivity (economic output per unit of energy used) or a fall in energy intensity (energy use per unit of economic output), and can refer to both primary and final energy. The development path of energy efficiency has a directly impact on the correlation between economic growth and energy consumption. To decouple economic growth and energy consumption requires an increase in energy efficiency for the economy as a whole.

In Germany, energy productivity relative to GDP has increased at a somewhat faster rate since 1990 than GDP itself.[2] Primary energy productivity improved by an average of 1.7 percent per year between 1990 and 2013.[3] Consequently, despite increasing economic output (1.4 percent per year on average) a slight reduction in primary energy consumption (–0.3 percent per year) was possible (see Figure 1). However, the improvement in efficiency has slowed in recent years: primary energy productivity grew by an annual average of 2.2 percent between 1990 and 2000, but only by 1.3 percent between 2000 and 2013.

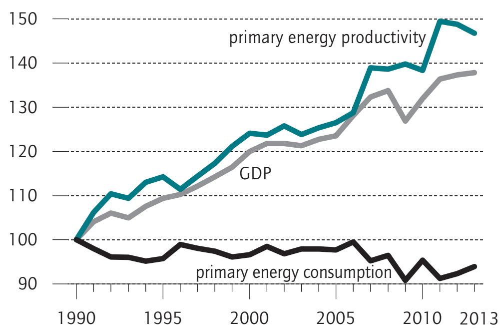
1 Directive 2012/27/EU of the European Parliament and of the Council of October 25, 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

2 Non-temperature-adjusted calculations by DIW Berlin based on data from the Working Group on Energy Balances (AGEB) and the German Federal Statistical Office.

3 No data on final energy consumption for 2013 are available yet. Between 1990 and 2012 final energy productivity improved by an average of 1.7 percent per year and primary energy productivity by an average of 1.8 percent per year. The slightly higher increase in primary energy efficiency can be attributed, inter alia, to the expansion of renewable energy sources, which has reduced primary energy consumption relative to final energy consumption.

Figure 1

Primary Energy Consumption, Primary Energy Productivity,[1] and GDP[2]
Index 1990 = 100[3]



1 Primary energy productivity (= GDP per unit of primary energy consumption) and primary energy consumption are not temperature adjusted.
2 In 2005 prices. 1990 estimated.
3 Provisional values for 2012 and 2013.
Sources: Arbeitsgemeinschaft Energiebilanzen; Federal Statistical Office; calculations by DIW Berlin.

Energy productivity increased slightly more sharply than GDP.

German Government's Efficiency Targets Are Far Reaching

In its 2010 Energy Concept, the German government formulated detailed and far-reaching targets to enhance energy efficiency.[4] For instance, with economic output continuing to increase, the aim is to reduce primary energy consumption by 20 percent by 2020 compared to 2008 and by 50 percent by 2050 and to increase final energy productivity by 2.1 percent per year.[5] The latter corresponds to a 0.4-percent rise in comparison to the average for the years 1990 to 2012.

A separate savings target of ten percent by 2020 and 25 percent by 2050 compared to 2008 was set for power consumption. In the transport sector, around ten percent of final energy consumption is to be saved by 2020 and around 40 percent by 2050 in comparison to the base year 2005. In the building sector, the objective is to achieve a virtually climate-neutral building stock by 2050. A further target is to double the rate of building renovation to upgrade energy performance from approximately one percent[6] to two percent per annum thus reducing the heat requirements of buildings by 20 percent by 2020 in comparison to 2008 and primary energy demand by as much as 80 percent by 2050.

Increasing energy efficiency—together with greater use of renewable energy sources in all areas of application—is considered to be a pillar of the energy transition.[7] The development of energy efficiency plays a crucial role in achieving the German government's climate policy targets. A high proportion of overall energy consumption contributed by renewable energy sources can be more easily achieved with a marked increase in energy efficiency.

Heat Sector of Particular Importance

In 2011, the industrial share of final energy consumption was around 30 percent (see Figure 2) and that of the transport sector was almost as high (29 percent).[8] Consumption by households accounted for 26 percent and consumption by trade, commerce, and the service sector for the remaining 15 percent. Accordingly, all sectors are expected to contribute to achieving the German government's far-reaching efficiency targets. The heat sector is of particular importance here. Space heating and hot water supply together accounted for over 30 percent of total final energy consumption in 2011. Mechanical energy, used mainly in the transport sector, also contributed a high share. Lighting as well as information and communication technology, often associated with power-saving measures in households, together accounted for a good six percent of final energy consumption.

4 BMWi and BMU, Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung (Berlin: Federal Ministry for Economic Affairs and Energy, Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, September 28, 2010).

5 Here, the German government has assumed an average economic growth of 0.8 percent per annum. See J. Nitsch et al., Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global. Final Report (German Aeronautics and Space Research Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR), Fraunhofer Institute for Wind Energy and Energy System Technology (Fraunhofer Institut für Windenergie und Energiesystemtechnik, IWES), Ingenieurbüro für neue Energien (IfnE), March 29, 2012), 47. Study conducted on behalf of the Federal Environment Ministry (BMU). With higher growth rates, there would have to be a correspondingly higher increase in energy productivity in order to achieve the reduction target for primary energy demand.

6 The estimate of the current rate of renovation is based on the study by the Institute for Housing and the Environment (IWU) and the Bremer Energie Institut (BE), Datenbasis Gebäudebestand, Datenerhebung zur energetischen Qualität und zu den Modernisierungstrends im deutschen Wohngebäudebestand (Darmstadt: 2010). It is also being critically debated whether this rate is reliable enough to serve as a policy objective. On this, see the Cologne Institute for Economic Research (IW), "Energetische Sanierung: Quote ohne Aussagekraft, "Immobilien-Monitor, no. 1 (March 13, 2012).

7 See. F. Schafhausen, "Die Energiewende – Aufbruch in die Zukunft," Vierteljahrshefte zur Wirtschaftsforschung, vol. 82, no. 03 (2013): 11–28.

8 The structure of the final energy consumption by sector for 2012 is now available. According to this data, at 27 percent, households had a somewhat higher share of the final energy consumption in 2012 than in the previous year while the shares of industry and transport decreased slightly. This can, inter alia, be attributed to a weather-related higher space heating requirement.

Scenario Analyses: How Does an Increase in Energy Efficiency Impact on the Economy?

As part of the framework of a research project, DIW Berlin analyzed the economic effects of an accelerated increase in energy efficiency in households and the manufacturing industry as well as trade, commerce, and the service sector.[9] As a first step, the economic stimuli which are associated with measures to enhance energy efficiency were derived. Then, possible economic consequences were quantitatively simulated in the form of scenarios using the SEEEM modeling instrument (see Box 1). Here, the focus was on energy upgrades for existing residential buildings.

In a modernization scenario, doubling the rate of building renovation to upgrade energy performance in line with the German government targets was assumed; conversely, the rate of renovation in a reference scenario remains unchanged. In addition to a baseline version of the modernization scenario, three alternatives were also studied in order to take into account uncertainties in view of shorter periods of repayment required by investors, lower energy savings, and higher specific investment costs.

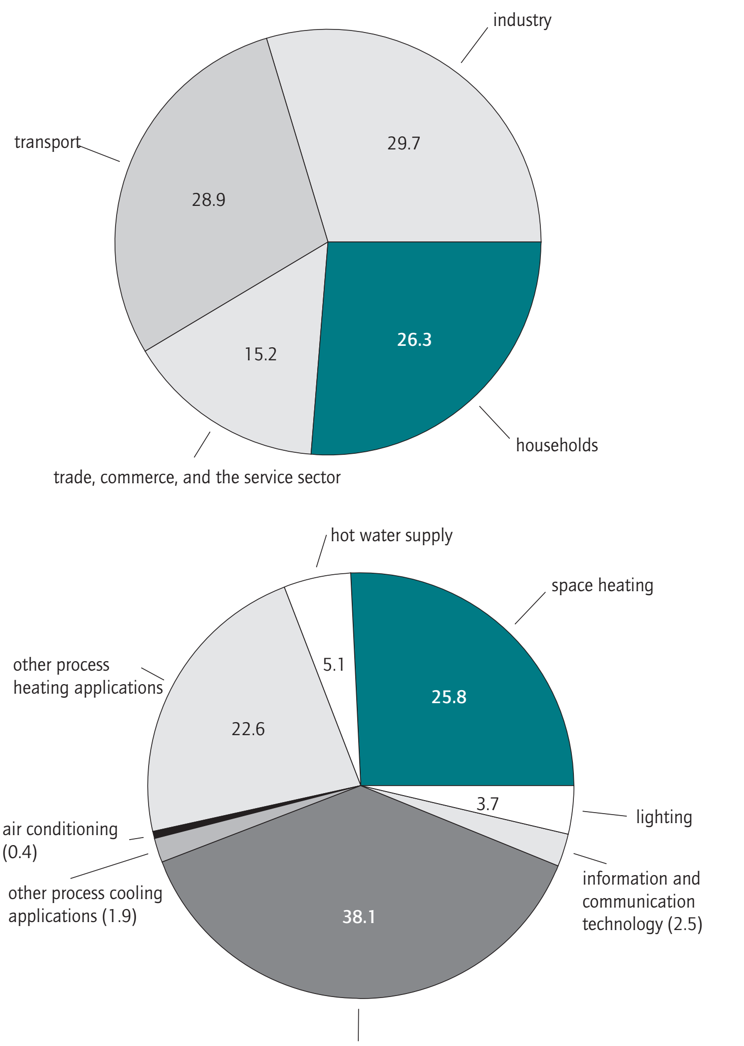
In addition, other economic measures to increase energy efficiency in households and the manufacturing industry as well as trade, commerce, and the service sector were included.[10] The economic stimuli resulting from these measures were taken from the literature. Here, it was assumed that these measures were implemented in the same way in all versions of the modernization scenario (see Box 2).

Renovation of Buildings Can Make an Important Contribution

Against the background of the targets mentioned above, energy upgrades for existing buildings can make an important contribution to the increase in overall energy efficiency. The starting point for assessing the energy-related investment in modernization in the building sector is structural information on existing residential buildings in Germany, estimates of the living space to be modernized, and information on the amount of capital expenditure needed per square meter of living space. The rate of building renovation to upgrade energy performance is used as an indicator of the scale of renovation. It is calculated as a weighted average on the basis of possible individual measures (for example, insulation

Figure 2

Final Energy Consumption by Economic Sector and Area of Energy Use 2011[1]
Share in percent



1 The structure of final energy consumption by economic sector is available for 2012 but the structure by areas of energy use is not.
Source: Arbeitsgemeinschaft Energiebilanzen.

Space heating and hot water supply constitute well over 30 percent of final energy consumption.

9 adelphi, DIW Berlin, and Fraunhofer ISI, Ökologische Modernisierung der Wirtschaft durch eine moderne Umweltpolitik. Project on behalf of the Federal Environmental Agency (UBA), project number (UFOPLAN) 3710 14 101. The final report is published by the UBA.

10 Improvements in efficiency in the transport sector which are undoubtedly necessary and beneficial were not studied as part of DIW Berlin's sub-project. On current developments in road transport, see U. Kunert and S. Radke, "Nachfrageentwicklung und Kraftstoffeinsatz im Straßenverkehr: Alternative Antriebe kommen nur schwer in Fahrt," Wochenbericht des DIW Berlin, no. 50 (2013).

Box 1

The SEEEM Modeling Instrument

DIW Berlin's Sectoral Energy-Economic Econometric Model (SEEEM) is used for the quantitative scenario analysis. This is based on the macroeconomic multi-country model of the National Institute Global Econometric Model (NiGEM) developed by the British National Institute of Economic and Social Research and was expanded at DIW Berlin by adding a sectoral submodel for Germany.

The equations of this neo-Keynesian model are theoretically consistently derived and include parameters which are estimated econometrically using error correction specifications. The model makes it possible to study the macroeconomic and sectoral knock-on effects of economic stimuli and permits to map out both short- and long-term effects. After exogenous shocks, there is a gradual shift toward long-term equilibriums in the model.

SEEEM has been used in the past to analyze the economic effects of expanding renewable energy sources in Germany.[1]

In the present study, it is used to examine the effects of various energy efficiency paths. Here, the direct economic stimuli associated with different scenarios to increase energy efficiency are fed into the model as exogenous parameters. The differences between various scenarios can be interpreted as effects of the change in stimuli.

For 2030 to 2050, the long-term effects of the stimuli from previous years and the effects of further stimuli were evaluated on the basis of the model results up until 2030. As a rule, all models used to estimate the effects of environmental policy strategies and other strategies are based on the assumption that key behavioral patterns and structures of the past also remain valid in the future. The further into the future these estimates extend, the less likely it is that this prerequisite is fulfilled. Therefore, assessments of the long-term effects of measures to enhance energy efficiency are subject to distinctly increasing uncertainties.

1 See J. Blazejczak, F.G. Braun, D. Edler, and W.-P. Schill, „Ausbau erneuerbarer Energien erhöht Wirtschaftsleistung in Deutschland," Wochenbericht des DIW Berlin, no. 50 (2010); and J. Blazejczak, F.G. Braun, D. Edler, and W.-P. Schill, „Economic Effects of Renewable Energy Expansion: A Model-Based Analysis for Germany," DIW Discussion Paper no. 1156 (2011).

of outer wall, insulation of roof/top floor ceiling, insulation of floor/cellar roof, or window replacement), with the weighting reflecting the heating energy saving resulting from the individual measures.[11]

Energy Upgrades of Living Space Must Be Doubled

In order to achieve the above-mentioned targets of the energy concept targets, a significant acceleration of activities in the field of building renovation to upgrade energy performance is required, so that ultimately the energy upgrades to existing buildings will be doubled from around one percent to date to two percent in future.

According to information provided by the Institute for Housing and the Environment (IWU) for 2011,[12] there were around 18 million residential buildings in Germany (up to construction year 2009), made up of 39.4 million homes with 3.415 billion square meters of living space. Around 36 percent of single- and multi-family houses as well as a good 30 percent of apartment blocks were built after the introduction of the first Thermal Insulation Ordinance of 1977 and consequently already met certain minimum standards regarding energy consumption at the time of construction.

11 For details of the methods of calculating the renovation rate, see the Institute for Housing and the Environment (IWU) and the Bremer Energie Institut (BE), Datenbasis Gebäudebestand. Individual measures related to energy upgrades on existing buildings are carried out significantly more frequently than full refurbishments to improve energy performance. Individual measures are carried out on around three percent of the residential building stock each year, also taking modernization of heating systems into account.

12 See the Institute for Housing and the Environment (IWU), Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie des IWU: Neufassung (August 2011). According to more recent data which are also based on analysis of the 2011 Census, the benchmark figures have changed slightly. The building stock is now estimated at 18.2 million residential buildings, encompassing 39.2 million homes with a living space of 3.552 billion m^2. On this, see the Institute for Housing and the Environment (IWU), Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie des IWU (2013): revised version, October 2013.

Box 2

Further Measures to Enhance Energy Efficiency

In addition to energy upgrades to buildings, there is further potential to increase energy efficiency in households. Some examples are energy saving through technical improvements to household appliances and lighting. There is considerable potential to save energy in trade, commerce and the service sector through energy upgrades to non-residential buildings as well as in areas of technology such as efficient lighting, office equipment, or improved refrigeration and freezer systems. In the industrial sector there is a particularly broad and diverse potential for fuel- and electricity-specific energy-saving technologies. These include both technologies that can be used in many sectors (cross-sectional technologies), and technologies for application in individual sectors, for example, in energy-intensive fields such as the chemicals industry or the paper industry.

Due to the large number of technologies that must be taken into consideration, no independent detailed assessment of investment in modernization and the associated energy savings was included. Instead, existing studies were evaluated,[1] in which measures to increase energy efficiency, excluding energy upgrades to residential buildings, were examined in detail. According to these analyses, there is a huge potential in the industrial sector for efficiency measures which can be developed at a low cost but which are subject to high return requirements with short repayment periods. Measures in this field are therefore assumed to be characterized by rather lower investment and relatively high energy savings.

In the areas summarized, excluding energy upgrades to residential buildings, investment in measures to enhance energy efficiency in 2020 amount to 4.2 billion euros. This is expected to increase to 4.7 billion euros in 2030 and subsequently remain constant in real terms. Approximately half of this figure is made up of investment in energy upgrades to non-residential buildings and half is investment in other—mainly electricity-related—measures. The energy cost savings in 2020 are anticipated to amount to 6.4 billion euros and are expected to rise by 2050 to 14.5 billion euros. The estimates for both investment and energy cost savings for the sectors considered collectively here are subject to greater uncertainties than the corresponding estimates for energy upgrades to residential buildings.

1 See WWF Germany, Modell Deutschland, Klimaschutz bis 2050: Vom Ziel her denken, a study by Prognos and Öko-Institut on behalf of the WWF (Berlin, Basel: 2009),; and M. Pehndt et al.: Energieeffizienz: Potenziale, volkswirtschaftliche Effekte und innovative Handlungs- und Förderfelder für die Nationale Klimaschutzinitiative, final report for the project "Wissenschaftliche Begleitforschung zu übergreifenden technischen, ökologischen, ökonomischen und strategischen Aspekten des nationalen Teils der Klimaschutzinitiative," (Heidelberg, Karlsruhe, Berlin, Osnabrück, and Freiburg: IFEU, Fraunhofer ISI, Prognos, GWS et al., 2011).

The future demand for buildings[13] essentially depends on demographic trends and household structure, particularly average household size. Although a marked decrease in the population of Germany is highly probable in the long term,[14] an increased demand for living space is anticipated up until 2030, followed by a decrease.[15] Living space is expected to increase to 3.7 billion square meters by 2030 and then drop again slightly to 3.6 billion square meters in 2050.

Renovation work on existing buildings varies according to the age and type of building. In addition, it has to be taken into account that the rates of renovation change over time. Very little modernization is required for new buildings; as buildings become older, the rate of renovation increases. As regards buildings which are already old now, the share of renovations carried out on them is initially high but the rate of renovation decreases in the long term. In the reference scenario, the rate of renovation for the entire building stock remains constant over time at well over one percent (see Table 1).

13 In the following, all modernization work refers to the building stock available in 2009. However, the modernizaton rates reported refer to the relevant total building stock. Physical depreciation or obsolescence from the existing building stock is not modeled here.

14 According to various versions of the 12th coordinated population projection by the Federal Statistical Office, the population of Germany is likely to drop from a good 80 million people at present to 77 to 79 million in 2030 and 69 to 73 million in 2050.

15 A crucial factor affecting this development is the significantly increasing proportion of one-person households of the total number of households, which leads to an increase in the per capita demand for living space.

Table 1

Rate of Building Renovation to Upgrade Energy Performance in the Reference and Modernization Scenarios
In percent

	Completion of building					
	Before 1957	1958–1983	After 1983	Before 1957	1958–1983	After 1983
	Single and multi-family houses			Apartment blocks and large apartment blocks		
Reference scenario						
2020	1.3	1.1	0.1	1.3	1.3	0.8
2030	1.1	1.0	0.5	1.3	1.2	1.0
2050	0.8	0.8	1.3	0.9	1.1	1.3
Modernization scenario						
2020	2.6	2.2	0.2	2.6	2.6	1.6
2030	2.3	2.0	1.0	2.6	2.4	2.0
2050	1.7	1.6	2.6	1.8	2.1	2.6

Source: calculations by DIW Berlin.

Renovation rates vary considerably depending on building type and age.

Table 2

Additionally Modernized Living Space with Doubled Rate of Building Renovation to Upgrade Energy Performance
Differences between modernization and reference scenario

	2020	2030	2050
In million m²			
Modernized residential space per annum	35.7	37.6	36.1
Existing modernized residential space	247.1	614.4	1,349.5
In percent			
Modernized residential space as share of total existing housing	7.0	16.7	37.3

Source: calculations by DIW Berlin

The total modernized residential space is expected to increase substantially over time.

In the modernization scenario, following an initial phase,[16] the rate of renovation remains permanently doubled in comparison to the reference scenario at around two percent. Growth of this magnitude results in a significant increase in the living space that has been renovated to upgrade energy performance (see Table 2). The annual additionally modernized living space in the modernization scenario amounts to a good 35 million square meters. The total area of additionally modernized living space in 2030 is 614 million square meters, while the corresponding figure for 2050 is 1.3 billion square meters. Measured in terms of building stock in the relevant year, compared to the reference development, an additional almost 17 percent of buildings will be modernized in 2030 and a good 37 percent in 2050.

Accelerated Pace of Energy Upgrades to Buildings Requires Considerable Additional Investment

The annual additional investment required for an accelerated pace of energy upgrades to buildings is calculated on the basis of the additionally modernized area and the specific costs of energy upgrades to buildings per unit of area. The specific renovation costs take the energy-related additional costs into account rather than the full costs (see Box 3). Due to the diversity of the different renovation projects and the dependence of the specific costs on the type of building,[17] the individual modernization costs can generally only be estimated with a degree of uncertainty. Based on the evaluation of numerous studies,[18] depending on the type and age of the building, specific energy-related additional costs are calculated here as between 160 and 220 euros per square meter. In real terms, this means that relative to the general price development in the economy, a cost increase of 1.5 percent per year from 2020 and of 2.5 percent from 2030 is assumed, since buildings that require more specific and costly renovation work are increasingly being upgraded in the course of time. Therefore, it is presumed that from about 2020 onwards the particularly low-cost renovation options will be increasingly exhausted and technological progress will not be sufficient to meet the increased modernization requirements. On this basis, the annual additional investment in energy

16 In the initial phase of accelerated energy upgrades to existing buildings, consideration must also be given to making the expansion of the necessary capacities in the building construction and finishing trades as smooth as possible. Observations by DIW Berlin have shown that considerable efforts and a well-timed phase of expansion of capacity are necessary for this. On this, see M. Gornig, H. Hagedorn, and C. Michelsen, "Bauwirtschaft: Zusätzliche Infrastrukturinvestitionen bringen zunächst keinen neuen Schwung, " Wochenbericht des DIW Berlin, no. 47 (2013).

17 The specific costs are, for example, lower for multi-family houses than for single-family houses and other building characteristics also play a crucial role.

18 See the Institute for Housing and the Environment (IWU), Wirtschaftlichkeit energiesparender Maßnahmen im Bestand vor dem Hintergrund der novellierten EnEV (Darmstadt: 2008); Dena, dena-Sanierungsstudie. Teil 1: Wirtschaftlichkeit energetischer Modernisierung im Mietwohnungsbestand. Begleitforschung zum dena-Projekt „Niedrigenergiehaus im Bestand" (Berlin: 2010); empirica, LUWOGE consult, Wirtschaftlichkeit energetischer Sanierungen im Berliner Mietwohnbestand (Berlin, Ludwigshafen: 2010); Arbeitsgemeinschaft, ed., Wohnungsbau in Deutschland 2011 – Modernisierung oder Bestandsersatz. Studie zum Zustand und der Zukunftsfähigkeit des deutschen „Kleinen Wohnungsbaus" (Kiel: 2011); the Cologne Institute for Economic Research (IW), Energetische Modernisierung des Gebäudebestandes: Herausforderungen für private Eigentümer, study conducted on behalf of Haus & Grund Deutschland (Cologne: 2012); prognos Ermittlung der Wachstumswirkungen der KfW-Programme zum Energieeffizienten Bauen und Sanieren, study conducted on behalf of the KfW Bankengruppe (Berlin, Basel: 2013).

Box 3

Concepts for Assessing the Costs of Measures for Energy Upgrades to Buildings

With regards to costs of energy upgrades to buildings, a distinction should always be made between full costs and energy-related additional costs. As a rule, comprehensive energy upgrades are only carried out in combination with other renovation work on the building shell (coupling principle), partly because this is a decisive factor in the microeconomic profitability of the work. The energy-related additional costs comprise only costs which are incurred for measures in addition to pure maintenance work (for example, costs of thermal insulation to exterior walls or intermediate floors, including fixing). What is not taken into consideration are costs that would be incurred anyway (for example, costs of the required construction site facilities, scaffolding costs, repainting, etc.), i.e., costs which, although necessary for carrying out the modernization work, are not directly connected with energy saving. Because of the many possible constellations of renovations, the ratio of energy-related additional costs to full costs fluctuates considerably. After evaluating a large number of cost estimates, a metastudy comes to the conclusion that the proportion of energy-related additional costs to full costs ranges from 30 to 60 percent.[1] According to these observations, assuming energy-related additional investment amounting to 7.4 billion euros, in the modernization scenario in 2020, full investment costs could range from 12.3 to 24.7 billion. However, calculations made on the basis of the DIW Berlin's construction volume calculation suggest that the upper limit of the cost estimate, i.e., with a proportion of energy-related additional costs of around 30 percent of the full costs, should be considered to be the more realistic version.

1 See the Cologne Institute for Economic Research (IW), Energetische Modernisierung.

upgrades of residential buildings is expected to amount to 7.4 billion euros in 2020,[19] increasing to 9 billion euros in 2030 and 14 billion euros in 2050.

Sharp Increase in Energy Cost Savings in Residential Buildings Over Time

The energy cost savings resulting from the investment in modernization depend on the existing modernized living space, the specific energy savings, and the assumptions relating to energy price development. The specific energy savings can only be estimated with a degree of uncertainty due to the numerous factors which have an impact: depending on building type and age, specific final energy savings of 120 to 200 kilowatt-hours per square meter are taken as a basis.[20] With respect to the energy costs, an average price of seven cents for final energy used per kilowatt-hour is assumed for 2010. The further price development is based on the fuel price paths in Scenario A of the long-term scenarios for 2011,[21] so that this represents an increase in energy prices by 2050 that is twice as high as the increase in general prices. Based on these considerations, the energy costs saved for residential buildings will amount to 3.8 billion euros in 2020, while 11.1 billion euros will be saved in 2030 and 32 billion euros in 2050.[22]

Further Efficiency Measures in Other Sectors Require Additional Investment

Together with further additional investment and energy savings in other sectors (see Box 2), the estimated additional investment needed to accelerate the pace of energy upgrades for buildings and the energy costs saved results in all the economic stimuli studied in the baseline scenario of the modernization scenario. The additional investment required for energy efficiency in 2020 will amount to 11.6 billion euros, offset by total energy costs saved of 10.2 billion euros in the same year (see Table 3).[23] There is a significant rise in the energy costs

19 Unless otherwise stated, all information in the following refers to 2000 prices.

20 The specific energy savings can be derived from the studies quoted in footnote 18. See also F. Schröder et al., "Universelle Energiekennzahlen für Deutschland – Teil 1: Differenzierte Kennzahlverteilungen nach Energieträger und wärmetechnischem Sanierungsstand," Bauphysik 31, no.6 (2009): 393–402; and M. Greller et al., "Universelle Energiekennzahlen für Deutschland – Teil 2: Verbrauchskennzahlentwicklung nach Baualtersklassen, " Bauphysik 32, no. 1 (2010): 1–6.

21 See Nitsch et al., Langfristszenarien.

22 With owner-occupied housing, both the costs (in the form of funding energy-saving modernization) and the returns (in the form of energy costs saved) belong to the same economic unit. With rented housing, the owner bears the costs while the occupier profits (user/investor dilemma). In this case, the costs of energy-saving modernization must be recuperated from increases in the basic rent (not including utilities). Whether or not the necessary increase in this rent is feasible also depends, inter alia, on local rental market conditions.

23 If energy costs fall as a result of investment in energy efficiency, this may give energy consumers an incentive to use more energy. The size of this rebound effect is difficult to determine empirically. This effect is ignored in the present analysis.

Table 3

Investment for Accelerated Increase in Energy Efficiency and Additional Energy Cost Savings

Differences between modernization[1] and reference scenarios in billion euros[2]

	2020	2030	2050
Energy upgrades to residential buildings			
Investment	7.4	9.0	14.0
Energy cost savings	3.8	11.1	32.0
Measures in other sectors			
Investment	4.2	4.7	4.7
Energy cost savings	6.4	9.3	14.5
Total			
Investment	11.6	13.8	18.7
Energy cost savings	10.2	20.4	46.5

1 In the baseline version.
2 At 2000 prices.
Source: calculations by DIW Berlin.

There will be a much sharper increase in additional energy cost savings than additional investment.

saved over time because the stock of buildings on which efficiency measures have been carried out is constantly increasing. The investment needed also increases over time, albeit at a considerably slower rate. Investment in energy efficiency in 2030 is expected to amount to 13.8 billion euros, while the total energy cost savings in the same year are anticipated to be 20.4 billion euros. In 2050, energy cost savings of 46.5 billion euros are still only expected to be offset by additional investment of 18.7 billion euros.

Efficiency Measures Result In Significant Energy Savings and Reductions in Greenhouse Gas Emissions

The investment stimuli discussed earlier will result in significant energy savings. For 2020, savings of approximately 120 terawatt-hours are anticipated, compared to the reference scenario. The corresponding figure for 2030 is 214 terawatt-hours and 2050 will see savings of almost 400 terawatt-hours (see Table 4). Relative to Germany's total final energy consumption in 2012, these figures equate to additional savings of five percent in 2020, nine percent in 2030, and 16 percent in 2050.

Savings in the field of space heating applications are expected to be comparatively low initially. However, since it is anticipated that a constant building renovation rate of two percent will be maintained, this will lead to significant and constant growth in savings over time.[24] In other areas of energy use, on the other hand (particularly trade, commerce, and the service sector as well as industry) it is forecast that considerable energy savings potential will be realized as early as 2020 but that the growth of energy savings in this field will level off in the future.

Energy savings are accompanied by a reduction in greenhouse gas emissions. These are calculated on the basis of specific emission factors attributed to final energy consumption. For 2010, an emission factor of 0.28 kg CO_2 per kilowatt-hour of final energy consumption was assumed for heat energy consumption of residential buildings.[25] This factor is anticipated to improve to a value of 0.12 kg CO_2 per kilowatt-hour by 2050 due to a less emissions-intensive energy mix.[26] The same factor was also used to estimate the reduction in greenhouse gas emissions produced by fuel consumption in trade, commerce, and the service sector, and in industry. Electricity use is assigned a specific emission factor, which—particularly as a result of increased use of renewables—is expected to improve from around 0.6 kg CO_2 per kilowatt-hour in 2010 to 0.34 kg CO_2 per kilowatt-hour in 2030, and to continue to decline subsequently.[27]

It is envisaged that the investment stimuli modeled could result in an additional 45 million tonnes of CO_2 savings in 2020, compared to the reference scenario (see Table 4). The equivalent saving in 2030 would be 59 million tonnes and 74 million in 2050. Relative to total greenhouse gas emissions in 2012, this corresponds to a saving of five percent by 2020, six percent by 2030, and eight percent by 2050.[28] Initially, savings predominantly result from more efficient electricity usage in trade, commerce and the service sectors, and in industry. However, over time, there is an increase in the significance of savings made in the space heating of households due to the constantly growing number of existing residential buildings that are upgraded. As far as power is concerned, a drop in annual emission reductions is recorded over time as the electricity mix produces significantly fewer emissions.

24 Based on the assumption that the specific energy savings in kWh/m^2 remain constant over time.

25 Here and in the following, always CO_2 equivalent.

26 See IW Köln, Energetische Modernisierung des Gebäudebestandes (2012).

27 Shell, ed., Shell Hauswärme-Studie – Nachhaltige Wärmeerzeugung für Wohngebäude. Fakten, Trends, Perspektiven (Hamburg: 2011).

28 In the long-term, the relative savings in greenhouse gases should be lower than savings in energy consumption since, as renewable energy sources are used increasingly, the CO_2 intensity of energy supply will significantly decline over time.

Table 4

Energy Saving and Reduction in Greenhouse Gas Emissions

Differences between modernization[1] and reference scenarios

	2020	2030	2050
Energy in terawatt-hours(TWh)			
Residential space heating	39	96	206
Other forms of energy	80	117	186
Fuels	33	52	82
Electricity	48	65	103
Total	**119**	**214**	**391**
Greenhouse gas emissions in million tons of CO_2			
Residential space heating	10	24	43
Other forms of energy	34	35	31
Fuels	9	13	17
Electricity	26	22	14
Total	**45**	**59**	**74**

1 In the baseline version.
Source: calculations by DIW Berlin.

The energy savings and reduction in greenhouse gas emissions will be significant.

Table 5

Economic Effects of Additional Measures to Enhance Energy Efficiency

Differences between modernization[1] and reference scenarios in percent[2]

	2020	2030	2050
GDP	0.5	0.7	1.0
Private consumption	0.3	0.4	0.9
Private capital investment (excluding residential construction investment)	0.5	0.4	0.3
Investment in residential construction	7.2	7.4	9.6
Public investment	3.3	3.3	2.8
Exports	0.0	0.0	0.0
Imports	0.3	0.0	−0.1

1 In the baseline version.
2 Calculated on the basis of constant prices.
Source: calculations by DIW Berlin.

GDP is consistently higher when measures to enhance energy efficiency are implemented.

Positive Income and Employment Effects

Measures to enhance energy efficiency result in reduced greenhouse gas emissions and primary energy savings and cut external costs. In addition, these measures might also exert a positive impact on income and employment.

Through the network of interdependencies represented in the SEEEM modeling instrument used (see Box 1), the economic stimuli resulting from the increase in energy efficiency will have an impact on the income of the economy and how this income is used (see Table 5). The rise in residential construction investment, private fixed investment, and public investment combined (almost one billion euros in 2020)[29] is expected to be slightly higher than the increase in direct investment expenditure for further measures to enhance energy efficiency.

This can be explained by the fact that the additional investment results in expansionary effects that are greater than the damping effects that also occur. Expansionary effects mainly evolve as a result of multiplier and accelerator effects. The former occur because the additional income generated in producing the additional investments will then be spent again which, in turn, further increases demand. The latter are a result of companies investing in the capital goods necessary to increase their output capacity. Damping effects can be caused, for example, by financial or real crowding out effects occurring when high borrowing requirements lead to deteriorations in credit conditions or shortages in personnel or equipment.

The additional income generated by higher output leads, in turn, to greater private consumption. Initially, the effect on imports will be dominated by the expansion of domestic demand, and the savings in energy costs and resultant reduction in imports are likely to remain minimal in 2020. Later, once the energy cost savings are higher due to a larger number of upgraded buildings, on balance, the imports are likely to be slightly less than in the reference scenario. Essentially, the reduction in fuel imports will be substituted by higher imports of other goods, however. There will be little change in exports.

After 2030, the stimuli which, on balance, have expansive effects will continue to increase due to the additional investment in enhancing energy efficiency and to energy cost savings. Consequently, the positive impact on income and consumption is also greater. In 2050, with further measures to improve energy efficiency, in real terms, GDP is anticipated to be around one percent higher than in the reference scenario.

One decisive factor for increases in income is that, in combination with measures to enhance energy efficien-

29 Unless otherwise stated, the following figures refer to the difference between the modernization scenario (baseline version) and the reference scenario.

cy, additional economic resources could be mobilized to create additional value-added. This could either be generated by activating additional labor or by accelerating productivity gains.[30] Additional labor can either be drawn from the ranks of the unemployed or the non-working population. If there is a risk of wage increases due to structural discrepancies between labor supply and demand, this might encourage companies to make better use of the potential for productivity growth. In the longer term, a simultaneous increase in output and productivity can be expected by the accelerated diffusion of innovations that occurs when growth is higher.

Should neither an increase in labor productivity nor the mobilization of additional labor be possible, thus preventing an increase in value-added, then—as long as foreign trade remains unchanged—additional investment to enhance energy efficiency would only be possible at the expense of other investment or private consumption.

Employment Effects Depend on Labor Market Conditions

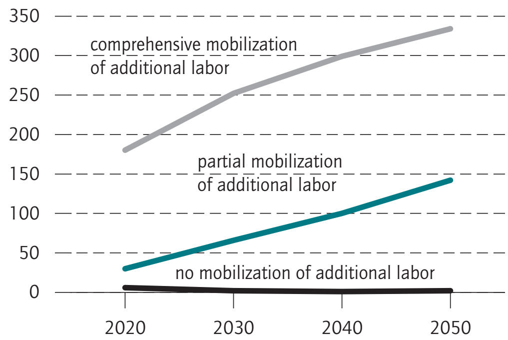
If productivity increases at the same pace as value-added, accelerated energy efficiency measures are unlikely to have any appreciable impact on net employment. If, however, value-added is not only facilitated by productivity gains but, to a certain extent, also by the mobilization of additional labor, palpable employment effects are possible. This would create around 30,000 more jobs in 2020 and 66,000 in 2030 (see Figure 3). In the period that follows, the employment effects could continue to grow, particularly if, over the course of time, more additional labor can be mobilized and the potential for further productivity growth decreases.

If there is no potential for productivity gains but, at the same time, there is unlimited availability of suitable additional labor[31] (and there are no feedback effects either due to rates of pay or foreign trade, for example), with identical stimuli and comparable effects on GDP, there could be an increase in employment of up to 180,000 people in 2020 and approximately 250,000 by 2030. In the long term, in this extreme case, the employment effect might even increase to over 300,000 people.

Figure 3

Possible Employment Effects of Further Measures to Enhance Energy Efficiency

1,000 people[1]



1 Differences between the modernization and reference scenarios based on different assumptions regarding the recruitment of additional labor. All variants are based on identical economic stimuli and comparable effects on GDP.
Source: calculations by DIW Berlin.

Significant positive employment effects are possible.

Positive Economic Effects Even Under Different Conditions

The economic effects depend on a series of external conditions, the future development of which is uncertain. This applies in particular to the repayment periods required by investors, achievable energy savings, and to specific investment costs. First, it is unclear whether the repayment period of 20 years assumed in the baseline version provides enough incentives for investment in energy efficiency in residential buildings. If the investor intends to amortize his additional investment in energy efficiency within a ten-year period,[32] the capital costs would initially exceed the energy savings. Only from 2030, when a larger share of the investments will have already been amortized, are net cost savings likely to be higher than in the baseline version. The initially higher costs will be borne by households; consequently, purchasing power will be transferred to companies in the residential construction sector, which will then not be available for private consumption. For this reason, to begin with, shorter repayment periods result in growth in private consumption that is lower than in the baseline version, whereas it is subsequently higher (see Table 6). Imports demonstrate a very elastic response to changes in private consumption. Foreign goods account

30 What is meant here is per capita productivity; this increases in line with the average working hours or productivity per working hour.

31 For qualification requirements in the field of building renovation to upgrade energy performance see F. Mohaupt et al., " Beschäftigungswirkungen sowie Ausbildungs- und Qualifizierungsbedarf im Bereich der energetischen Gebäudesanierung," Reihe Umwelt, Innovation, Beschäftigung des BMU und UBA, no. 1/11 (Berlin and Dessau: 2011).

32 With a real annual interest rate on residual debt of 2.5 percent (unchanged compared to the baseline version).

for a significant share of the increase or decrease in consumption. The changes in consumption therefore only result in increases or decreases in domestic value-added to a limited extent; the effects on GDP and employment only vary slightly with different repayment periods.

The magnitude of energy savings that can be achieved with a specific investment sum is also uncertain. If energy savings and the resultant reduction in fossil fuel imports in the housing sector is only half the level assumed in the baseline version (keeping investment levels the same), on balance, this would lead to increased costs over the entire period analyzed in comparison to the reference scenario. This, in turn, would lead to a marked reduction in the potential for additional consumption available to households. In contrast to the model with shorter repayment periods, the initially lower private consumption (compared to the baseline version) is not offset by higher consumption in later years. The knock-on effect on domesctic value-added and employment is cushioned by the highly elasticity of imports in relation to private consumption: although the increase in GDP is lower than in the baseline version, the difference is not as significant as with private consumption.

The effect is similar when energy upgrades to existing residential buildings result in higher costs. Assuming that specific investment costs are double those in the baseline version, this would result in a decline in disposable income and would also dampen private consumption, albeit to a lesser extent than the original stimulus. The reason for this is the multiplier effects of higher investment. Here, too, some of the additional demand (compared to the reference scenario) is satisfied by imports; this attenuates the impact on GDP and employment.

The size of the increase in income and employment also depends on other circumstances, such as fiscal policy. The higher income resulting from enhancing energy efficiency initially leads to additional tax revenue. In the versions of the modernization scenario described, it is assumed that the government will reduce taxes to offset this effect to the extent that its fiscal balances remain unchanged. Should the additional tax revenue be used to consolidate the national budget instead, the increase in income and private consumption would be lower.

Conversely, there could be a stronger increase in income if policy-makers based their decisions on past developments rather than available information about future developments, as is assumed here.[33]

Table 6

Economic Effects Based On Alternative Assumptions

Differences between modernization and reference scenarios in percent[1]

Assumptions		2020	2030	2050
Baseline version	GDP	0.5	0.7	1.0
	Private consumption	0.3	0.4	0.9
Shorter repayment periods	GDP	0.4	0.7	1.1
	Private consumption	0.1	0.5	1.3
Lower energy savings	GDP	0.4	0.5	0.7
	Private consumption	0.1	0.1	0.4
Higher investment costs	GDP	0.5	0.7	1.0
	Private consumption	0.1	0.0	0.3

1 Calculated on the basis of constant prices.
Source: calculations by DIW Berlin.

Even allowing for considerable elements of uncertainty, positive economic effects prevail.

Construction Industry Accounts for Lion's Share of Increased Output

The different sectors of the economy are affected to varying degrees by measures to enhance energy efficiency (see Figure 4).[34] The construction industry accounts for the largest share of output effects—anticipated to be almost 35 percent of the total additional gross output in 2020; this reflects the importance of energy upgrades as one of the measures to increase energy efficiency. However, over time, the contribution made by the construction industry will decline because households' energy cost savings noticeably increase the demand for other private consumption goods. Nonetheless, in 2050, the construction industry is expected to still account for more than a quarter of the additional gross output.

The manufacturing industry (excluding construction) accounts for the second highest share of growth effects—around 27 percent of gross output in 2020. However, relative to the significance of this sector for the economy, the impact on this branch is considerably weaker than on the construction sector. The manufacturing industry profits directly from increasing capital investment to improve energy efficiency outside the housing sector, but, since it supplies the intermediate inputs, it also benefits indirectly from increases in output in other branches of the economy. However, the share of

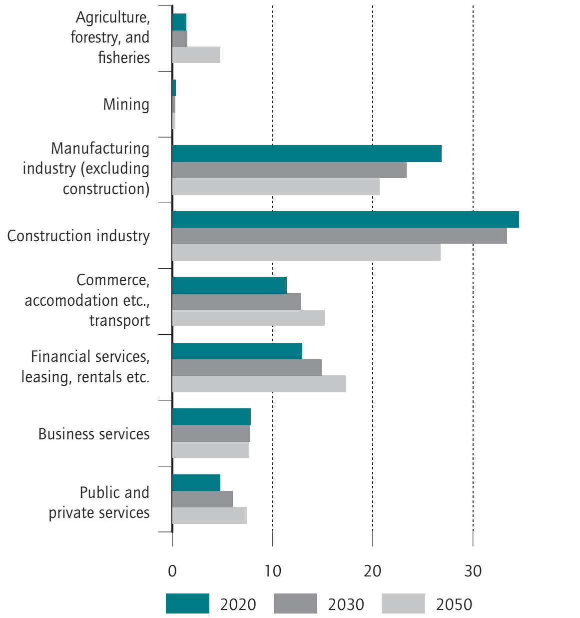
33 The SEEEM model enables us to depict both forward- and backward-looking expectation formation. A simulation based on the assumption of *backward-looking expectations* shows that the effect on GDP, particularly initially, is significantly greater than with *forward-looking expectations*; over time, developments in both scenarios converge to the results obtained under *forward-looking expectations*.

34 The following figures are taken from the baseline version.

Figure 4

Sectoral Distribution of Output Effects[1] of Further Measures to Enhance Energy Efficiency

Share of total output effect accounted for by respective sectors, in percent



1 Differences between the modernization scenario in the baseline version and the reference scenario.
Source: calculations by DIW Berlin.

The construction industry in particular has profited.

gross output gains accounted for by the manufacturing industry will decrease over time. The service sector increasingly profits from modernization over time as the second-round effects of the energy efficiency measures gain significance.

Conclusion and Implications for Economic Policy

Since 1990, Germany has enhanced energy efficiency: with rising GDP, primary energy consumption has declined slightly. However, in order to meet the German government's far-reaching energy saving and emissions reduction targets, as well as bring about the planned increased use of renewables, the previous rate of energy efficiency improvement is far from sufficient. Therefore, the German government aims to achieve a rise in the final energy productivity rate by an average of 2.1 percent per annum. Meeting this target will require the involvement of every sector of the economy. In the long-term, the renovation of existing residential buildings is of particular significance; the government aims to double the rate of building renovation to upgrade energy performance from one percent at present to two percent in the future.

Taking into account the different renovation requirements (depending on building age and type), it is possible to estimate the additional investment required for energy efficiency measures: the volume of investment is expected to be well over seven billion euros in 2020, nine billion euros in 2030, and 14 billion in 2050, all at 2000 prices. The extra investment consists of additional expenditure exclusively for energy upgrades to buildings. This would enable households to save almost four billion euros on their energy bills in 2020 (at 2000 prices). A saving of 11 billion euros is expected in 2030 and the corresponding figure for 2050 is 32 billion.

This, combined with further measures to improve energy efficiency in households, industry as well as trade, commerce, and the service sector could reduce energy consumption by 120 terawatt-hours by 2020 in comparison to the reference scenario, and the corresponding figure could be as high as almost 400 terawatt-hours by 2050. Compared to the reference scenario, greenhouse gas emissions could decline by 45 million tons by 2020 and this figure could be as high as 74 million tons by 2050.

Stimuli, in the form of additional investment and energy cost savings, resulting from measures to accelerate energy efficiency could have a positive impact on income and domestic demand, should it be possible to achieve additional production capacity through productivity gains or the mobilization of previously unemployed labor. GDP will increase by half a percent in 2020 and one percent in 2050, compared to the reference scenario. Most of the additional output is accounted for by the construction industry. This could result in significantly positive effects on employment, depending on the ratio of productivity gains and new jobs.

Slightly more limited but still positive income and employment effects will remain even with the requirement for shorter repayment periods for investments in energy upgrades to residential buildings, lower energy savings with the same investment requirements, or higher investments resulting from the same targeted increases in energy upgrades.

To date, policy-makers have not taken adequate account of the importance of enhancing energy efficiency for the success of the energy transition. If the government does not succeed in moving Germany onto a more ambitious energy efficiency path through additional incentives and measures, the existing climate targets and the renewable energy expansion targets (formulated as shares of energy consumption) will become much less achievable. The lack of success with regard to building renovation to upgrade energy performance is a particular problem area. Against a background of necessary capacity adjustments in the construction industry (and its supply sectors) as well as the advanced planning required for these adjustments, an acceleration of activities has to be gradual if friction and price increases are to be avoided. This underlines how important it is to create a clear and dependable framework soon to increase the number of buildings being renovated to upgrade energy performance. Any further hesitation will only increase the risk of tentativeness in investment decisions and diminish the window of time available for meeting the government's targets. Given the present analyses which indicate that forcing the pace of energy efficiency improvements has a positive impact on German economic growth and employment, the hesitation at the policy level seems even less justified.

Finally, measures to accelerate energy efficiency improvements—along with other elements of the energy transition,[35] measures to maintain an efficient transport infrastructure,[36] and increased investment in education[37]—are expected to contribute to increasing investment activity in Germany, thus closing the existing investment gap. This would strengthen German economic growth and also provide momentum for an upturn of the European economy.[38]

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JEL: Q41, Q43, Q48
Keywords: Energy efficiency, economic impacts, Germany

35 J. Blazejczak et al., "Energy Transition Calls for High Investment," DIW Economic Bulletin, no. 9 (2013).

36 U. Kunert and H. Link, "Transport Infrastructure: Higher Investments Needed to Preserve Assets," DIW Economic Bulletin, no. 10 (2013).

37 K. Spieß, "Investments in Education: The Early Years Offer Great Potential," DIW Economic Bulletin, no. 10 (2013).

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SEVEN QUESTIONS TO DIETMAR EDLER

»Energy Upgrades: the Longer You Wait, the Harder It Gets«

1. Dr. Edler, the energy transition is intended to enhance energy efficiency, among other things. What are the German government's targets? The government aims to achieve an average annual increase in energy efficiency of a good two percent long-term. If these targets are met, Germany will have accomplished far more than in the past. This makes it clear that additional efforts and measures are necessary.

2. Which areas are most promising for improving energy efficiency? Significant progress must be made in space heating in particular. This includes all energy upgrade measures that contribute to reducing energy consumption in buildings in general as well as in housing.

3. DIW Berlin conducted an analysis of the economic effects of accelerated increases in energy efficiency especially concerning energy upgrades for buildings. Is this likely to have a negative impact on the economy or possibly even result in an economic upturn? Our studies have shown that in the long term, the cost savings significantly outweigh the necessary capital investments. Increased measures in this area could serve as a stimulus for economic growth. If efforts to initiate these measures are successful, the German economy would grow more strongly in the medium and long term than without them.

4. How large are the effects on incomes and employment? Our studies show that stronger growth is linked to rising incomes and an increase in the value-added of the economy. The employment effects depend on various labor market conditions. The measures to increase energy efficiency take effect by making it possible to utilize new production factors of the economy, for example, by increasing labor productivity or recruiting additional labor.

5. The German government aims to double the rate of building renovation to upgrade energy performance. Does this mean the problem has been identified? The problem has been recognized, but the necessary measures that could help meet the goals set have not yet been taken. The longer you wait, the harder it gets to actually achieve the original targets. After all, these measures involve significant investment and thus also adjustments in the construction industry and other sectors of the economy. The longer you wait, the harder it gets to change course to the necessary path of modernization.

6. How high do you estimate the actual investment needs to be? Our analyses focus on examining the energy-related additional investments required for successful energy upgrades. According to our calculations, they amount to between seven and 14 billion euros. But those costs are offset by significantly higher energy savings. In the long term, cost savings far exceed annual investment.

7. How important is increasing energy efficiency in the context of the energy transition? Energy efficiency is the determining factor for the development of the economy's energy consumption overall. For example, targets for expanding renewables are measured against energy consumption. But if we do not succeed in lowering energy consumption by way of accelerated energy efficiency measures, as intended in the energy transition, it will also be very difficult to meet the targets set for increasing renewables as a fraction of energy consumption. This is why enhancing energy efficiency is of central importance to the energy transition.

Interview by Erich Wittenberg.

Climate Protection Through Biochar in German Agriculture: Potentials and Costs

by Isabel Teichmann

In recent years, there has been much discussion about biochar—a carbonaceous product made of biomass—as a promising technique for mitigating climate change. In particular, this method has the potential to remove carbon dioxide from the atmosphere for the long term by incorporating biochar into the soil while enhancing soil fertility at the same time.

A research project conducted by DIW Berlin calculated the greenhouse gas mitigation potential and possible costs of using biochar in German agriculture. According to this study, approximately one percent of the greenhouse gas reduction target for 2030 could be met using biochar, but largely at a cost of over 100 euros per tonne of CO_2. Ultimately, however, biochar's potential for reducing greenhouse gas emissions is limited by the availability of biomass. The possible agricultural benefits of biochar in the form of enhanced soil fertility could improve the greenhouse gas reduction potential and costs. This may be of particular relevance in tropical and subtropical regions.

The German government aims to reduce annual greenhouse gas emissions in Germany by 55 percent (compared to 1990 levels) by 2030 and by 80 to 95 percent by 2050.[1] In this context, biomass has been used so far in various forms as a regenerative source of energy for the production of electricity, heat, and fuels. Currently, it is discussed how biomass-derived biochar can contribute to climate protection in the future.

Biochar, also called black carbon,[2] is created by heating biomass in the near absence of oxygen (incomplete combustion). During this process, part of the biomass is decomposed into gaseous and liquid components. The remaining solid residue, which consists largely of stable carbon, is referred to as biochar. In very simple terms, biochar is charcoal, which can be produced not only from wood, but from any type of biomass, such as straw, green waste, biogenic household waste, liquid manure, digestates, or sewage sludge.

Like the original biomass, biochar can be used energetically and replace fossil fuels. Unlike the original biomass, it can also contribute to the long-term removal of carbon dioxide (CO2) from the atmosphere (carbon sequestration) by incorporating biochar into soils (see Figure 1).[3] The carbon in biochar is characterized by high

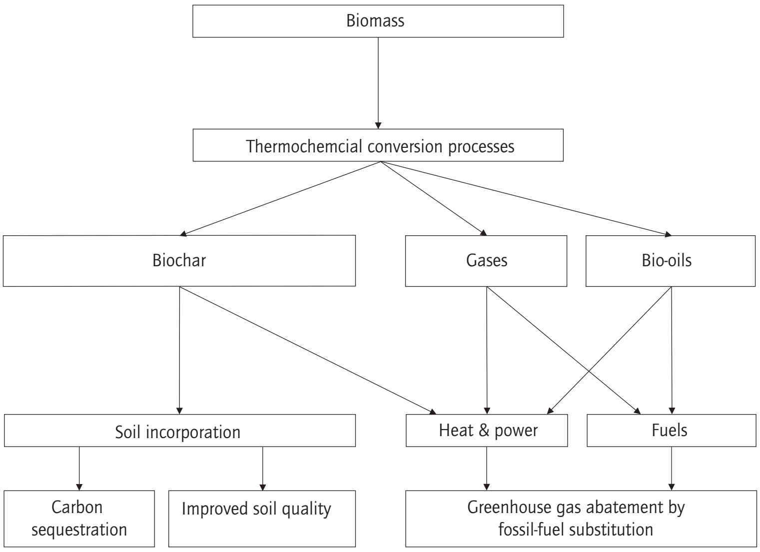
1 BMWi and BMU, eds., Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung, Federal Ministry of Economics and Technology (BMWi), Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) (2010).

2 Some authors use the term biochar only when referring to applications in agriculture and reserve the term charcoal for energy applications. See J. Lehmann and S. Joseph, "Biochar for Environmental Management: An Introduction, " in "Biochar for Environmental Management: Science and Technology," eds. J. Lehmann and S. Joseph, Earthscan (London, UK and Sterling, VA, United States: 2009): 1–12. This report follows a broader definition of biochar which includes energy use.

3 In this context, biochar is also discussed as a so-called climate-engineering measure, that is, as a targeted technical intervention in the climate system. See W. Rickels, G. Klepper, J. Dovern, G. Betz, N. Brachatzek, S. Cacean, K. Güssow, J. Heintzenberg, S. Hiller, C. Hoose, T. Leisner, A. Oschlies, U. Platt, A. Proelß, O. Renn, S. Schäfer, and M. Zürn, Large-scale intentional interventions into the climate system? Assessing the climate engineering debate, Scoping report

Figure 1

Biochar Flowchart[1]



1 The use of biochar to generate energy was not examined in this study.
Source: diagram by DIW Berlin.

The application of biochar in agriculture can abate greenhouse gas emissions and improve soil quality.

stability; chemical and biological processes take significantly more time to convert it back to CO_2 than the carbon in the original biomass.[4] In addition, biochar can improve the nutrient-retention and water-holding capacities of the soil.[5] Accordingly, its incorporation into the soil could contribute to improving soil quality and, thus, to increasing agricultural productivity. This is of great importance due to the rising global demand for food and energy crops, whereby soil quality is becoming an ever greater constraint, also in Europe and Germany.[6]

A well-known example of the lasting effect of biochar is the so-called Terra Preta do Indio, a particularly fertile dark earth occurring in spots throughout the Amazon Basin. Terra Preta is significantly different from the usual soils in the humid tropics because of its high levels of carbon and nutrients, such as nitrogen, phosphorus, and potassium, as well as its better nutrient-retention capacity. The Terra Preta soils date back to human activity in pre-Columbian times. In addition to animal and human excrements, bones, fish bones and turtle backs, Terra Preta contains a high percentage of biochar.[7] While most of the nutrients were probably introduced through organic waste,[8] the biochar is largely responsible for the high stability and persistent fertility of Terra Preta.

A research project conducted at DIW Berlin calculated the potentials and costs of carbon sequestration and greenhouse gas abatement based on the agricultural use of biochar from domestic biomass.[9]

Different Conversion Processes and Feedstocks

The yield of biochar and its specific properties are largely determined by the conversion processes and feedstocks used in its production.

Biochar Can Be Produced in Different Ways

Biochar is naturally occurring, for example, as a by-product of vegetation fires where oxygen supply is limited. For the industrial production of biochar, various thermochemical conversion processes are suitable (see Figure 2).[10] They range from the dry processes of pyrolysis and gasification to the wet process of hydrothermal car-

conducted on behalf of the German Federal Ministry of Education and Research (BMBF), Kiel Earth Institute, Kiel, 2011.

4 For example, J. Lehmann, C. Czimczik, D. Laird, and S. Sohi, "Stability of Biochar in the Soil," in "Biochar for Environmental Management: Science and Technology," eds. J. Lehmann and S. Joseph, Earthscan (London, UK and Sterling, VA, USA: 2009): 183–205. „

5 J. Lehmann, "Bio-Energy in the Black," Frontiers in Ecology and the Environment 5, no. 7 (2007): 381–387.

6 A. Jones, P. Panagos, S. Barcelo, F. Bouraoui, C. Bosco, O. Dewitte, C. Gardi, M. Erhard, J. Hervás, R. Hiederer, S. Jeffrey, A. Lükewille, L. Marmo, L. Montanarella, C. Olazábal, J.-E. Petersen, V. Penizek, T. Strassburger, G. Tóth, M. Van Den Eeckhaut, M. Van Liedekerke, F. Verheijen, E. Viestova , and Y. Yigini, The State of Soil in Europe: A Contribution of the JRC to the European Environment Agency's Environment State and Outlook Report – SOER 2010, JRC Reference Reports, EUR 25186 EN (Luxembourg: European Commission, 2012).

7 For example, B. Glaser, L. Haumeier, G. Guggenberger, and W. Zech, "The ‚Terra Preta' Phenomenon: A Model for Sustainable Agriculture in the Humid Tropics," Naturwissenschaften 88, no. 1 (2001): 37-41.

8 B. Glaser, "Prehistorically Modified Soils of Central Amazonia: A Model for Sustainable Agriculture in the Twenty-First Century," Philosophical Transactions of the Royal Society B 362, no. 1478 (2007): 187–196.

9 The analysis was carried out as part of the project "Biochar in Agriculture – Perspectives for Germany and Malaysia" funded by the Leibniz Association, www2.atb-potsdam.de/biochar/biochar_start.htm. The detailed assumptions and calculations will be published shortly in a DIW Discussion Paper.

10 Biochar can be produced in traditional ways in small, simple kilns. However, the following focuses on more sophisticated industrial technologies.

bonization (HTC).[11] While the biomass is heated without oxygen in the pyrolysis process, a small amount of oxygen is added in the gasification process. HTC differs fundamentally from these two processes in that water is added. Biochar produced by the HTC method is also called HTC char or hydrochar.

The biochar yield is determined by the conversion process as well as the specific reaction conditions, most importantly, the highest heating temperature and residence time. In particular, the average biochar yield decreases with an increase in the reaction temperature from slow pyrolysis to gasification. The highest biochar yields are obtained by the HTC method.

At the same time, the conversion process and reaction conditions determine the properties of the biochar. While the biochar yield decreases as the reaction temperature increases, the carbon content of the biochar increases in the reaction temperature.[12] Of the dry processes, the slow pyrolysis method transfers the most carbon from the biomass to the biochar.[13] Biochar from the dry processes is more stable than HTC char.[14]

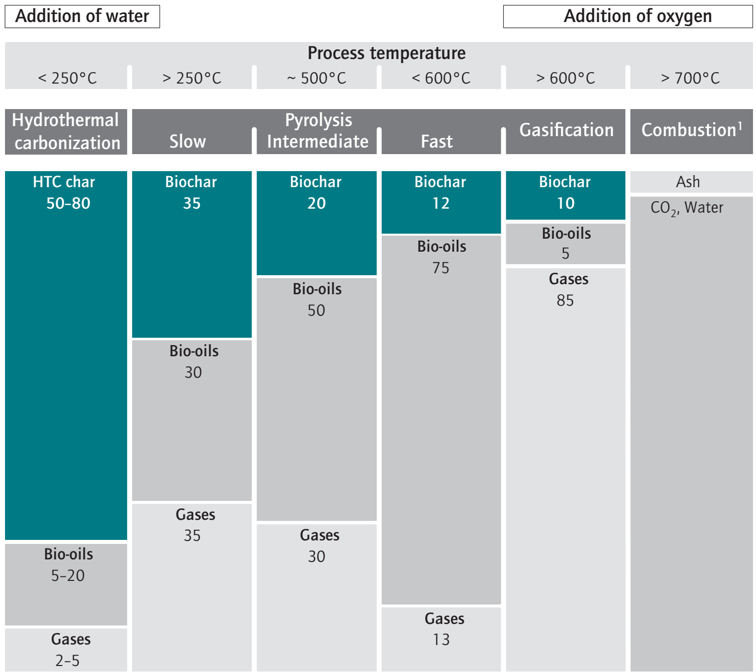
Therefore, biochar obtained from the (slow) pyrolysis process tends to be particularly suited for soil carbon sequestration, while the less stable HTC chars tend to be more advantageous for energetic uses. The gasification process is primarily aimed at extracting gases for energy purposes; however, if sufficient capacities were established, biochar from this process would also be suitable for carbon sequestration despite the lower biochar yield.[15]

From an economic perspective, HTC as a wet process seems advantageous for converting biomass with a high moisture content. In contrast to pyrolysis or gasification,

Figure 2

Thermochemical Conversion Processes for the Production of Biochar

Weight distribution in percent



1 No biochar is created during complete combustion It is only shown for comparison.

Sources: Quicker, "Thermochemische Verfahren," ORBIT, Weimar, (2012), 21-33; Libra et al., "Hydrothermal carbonization of biomass residuals," Biofuels 2(1), (2011): 89–124; DIW Berlin.

Biochar yields depend mainly on the process temperature.

the biomass does not have to be pre-dried at great expense in the HTC process.[16]

Biochar Properties Depend Significantly on the Type of Feedstock

In the trade-off between conversion process, yield, properties and intended use of biochar, the initial biomass also plays an important role. In particular, the yield and the carbon content of biochar are highly dependent on the chemical composition of the biomass. For a given conversion process, for example, higher biochar yields can frequently be achieved from feedstocks with a high ash content.[17] This means, however, that the cor-

11 J. A. Libra, K. S. Ro, C. Kammann, A. Funke, N. D. Berge, Y. Neubauer, M.-M. Titirici, C. Führer, O. Bens, J. Kern, and K.-H. Emmerich, "Hydrothermal Carbonization of Biomass Residuals: A Comparative Review of the Chemistry, Processes and Applications of Wet and Dry Pyrolysis," Biofuels 2, no. 1 (2011): 89–124.

12 For example, O. Mašek, P. Brownsort, A. Cross, and S. Sohi, "Influence of Production Conditions on the Yield and Environmental Stability of Biochar," Fuel 103 (2013): 151-155.

13 For example, K. B. Cantrell, P. G. Hunt, M. Uchimiya, J. M. Novak, and K. S. Ro, "Impact of Pyrolysis Temperature and Manure Source on Physicochemical Characteristics of Biochar," Bioresource Technology 107 (2012): 419–428.

14 For example, C. Kammann, S. Ratering, C. Eckhard, and C. Müller, "Biochar and Hydrochar Effects on Greenhouse Gas (Carbon Dioxide, Nitrous Oxide, and Methane) Fluxes from Soils," Journal of Environmental Quality 41, no.4 (2012): 1052–1066; S. Steinbeiss, G. Gleixner, and M. Antonietti, "Effect of Biochar Amendment on Soil Carbon Balance and Soil Microbial Activity," Soil Biology & Biochemistry 41, no. 6 (2009): 1301–1310; Y. Kuzyakov, I. Subbotina, H. Chen, I. Bogomolova, and X. Xu, "Black Carbon Decomposition and Incorporation into Soil Microbial Biomass Estimated by ^{14}C Labeling," Soil Biology & Biochemistry 41, no. 2 (2009): 210–219.

15 Libra et al., "Hydrothermal Carbonization of Biomass Residuals," 89–124.

16 Libra et al., "Hydrothermal Carbonization of Biomass Residuals," 89–124.

17 Cantrell et al., "Impact of Pyrolysis Temperature," 419–428.

responding biochar has a lower carbon content. At the same time, a higher ash content, as in liquid and solid manure, leads to a higher nutrient content of the biochar, which, in turn, is important for use in agriculture.

Multiple Benefits of Adding Biochar to Soils

If biochar is not used energetically, but added to soil, this might not only lead to a permanent sequestration of carbon, but also improve the quality of the soil. In addition, the conversion of biomass into biochar enables valuable recycling of biomass residues, such as liquid manure, which sometimes occur in such large quantities that a use in agriculture becomes difficult.[18] Moreover, biochar production results in both liquid and gaseous by-products, which can be used in renewable energy generation (see Figure 1).

Carbon Sequestration through Biochar

The soil incorporation of biochar can serve as a near-surface carbon sink due to the high content of stable carbon in the biochar.[19] As a rough estimate, about half of the carbon removed from the atmosphere through photosynthesis remains in the biomass; thereof, in turn, about half is recovered in biochar during pyrolysis.[20] Up to 80 percent of that carbon might remain stable in the soil long-term. Consequently, converting biomass into biochar, up to 20 percent of the carbon that was originally taken up by the plants through photosynthesis might be removed from the atmosphere for the medium to long term. Without transforming the biomass into biochar, the biomass carbon would be fully released over the life cycle of a plant—either through natural decomposition processes or through the energetic use of the biomass.[21]

However, it has not yet been possible to quantify the long-term stability of biochar in soil exactly. The stability depends on many factors, such as the biomass the biochar is made of, the specific conversion process, the soil the biochar is added to, and the climatic and environmental influences the biochar is exposed to. In general, soil processes are very complex and difficult to quantify.[22] In addition, the effect of carbon sequestration might be eliminated, for example, as soon as there is a fire on the site where the biochar was added to the soil. For an overview of the current options for determining the stability of biochar, see the box.

Agricultural Benefits Possible, But Not Certain

The introduction of carbon into the soil and biochar's capability to store nutrients and water particularly well could help improve the quality of the soil and, thereby, increase agricultural productivity. In this way, the addition of biochar could increase plant growth. Likewise, it could reduce the use of synthetic fertilizers. However, it has not yet been completely understood how biochar affects plant growth exactly, especially in the long term. A recent metastudy on the short- to medium-term effects of biochar shows an average yield increase of 10 percent, whereby the results range from -28 percent to +39 percent.[23] Thus, negative effects on plant growth cannot be ruled out. Ultimately, the effects depend on many factors, in particular, the plant species, the type and quantity of biochar added, the type of soil, and other environmental conditions. Generally, smaller growth impulses are expected in the temperate zone than in tropical or subtropical regions, which usually have less fertile soils.

Biochar and the Other Conversion Products Can Be Used Energetically

As an alternative to soil incorporation, biochar can also be used to produce energy.[24] This can be particularly useful if the transport or the direct energetic use of the original biomass are not practicable. For example, biochar can be co-combusted in conventional coal-fired power plants. The calorific values of biochar depend on the feedstock and the chosen conversion process. The conversion of wood into biochar in the pyrolysis process, for example, can result in calorific values of up to 30 megajoules per kilogram (MJ/kg), which corresponds

18 Libra et al., "Hydrothermal Carbonization of Biomass Residuals," 89–124.

19 In contrast, carbon capture, transport and storage (CCS or CCTS), whose practicability has been much discussed lately, involves sequestering CO_2 in geological depths. See C. von Hirschhausen, J. Herold, P.-Y. Oei, and C. Haftendorn, "CCTS-Technologie ein Fehlschlag: Umdenken in der Energiewende notwendig," Wochenbericht des DIW Berlin, no. 6 (2012).

20 J. Lehmann, "A Handful of Carbon," Nature 447 (2007): 143–144.

21 However, this comparison abstracts from a possible stabilization of biomass carbon through soil processes when biomass is introduced into the soil.

22 M. W. I. Schmidt, M. S. Torn, S. Abiven, T. Dittmar, G. Guggenberger, I. A. Janssens, M. Kleber, I. Kögel-Knabner, J. Lehmann, D. A. C. Manning, P. Nannipieri, D. P. Rasse, S. Weiner, and S. E. Trumbore, "Persistence of Soil Organic Matter As an Ecosystem Property," Nature 478 (2011): 49–56.

23 S. Jeffrey, F. G. A. Verheijen, M. van der Velde, and A. C. Bastos, "A Quantitative Review of the Effects of Biochar Application to Soils on Crop Productivity Using Meta-Analysis," Agriculture, Ecosystems and Environment 144, no. 1 (2011): 175–187.

24 In addition, biochar may be used as a material, for example, as a feed additive, as a reductant in metallurgical processes, or as a raw material for carbon fibers and plastic.

Box

Determining the Stability of Biochar

The proportion of biochar carbon that remains stable in the soil for the long-term is not precisely quantifiable. However, there are a number of methods for measuring the stability of biochar that provide estimates for possible orders of magnitude.

Some methods are based on the properties of the biochar itself. For example, there are various indicators of the content of stable carbon in the biochar. These include, among others, the share of fixed carbon, the ratio of oxygen to carbon,[1] or a combination of the volatile-matter content of the biochar with the ratio of oxygen or hydrogen to organic carbon.[2] In addition, a so-called recalcitrance index was developed to indicate the thermal stability of biochar compared to that of graphite.[3] The higher this index, the higher the carbon sequestration potential of the biochar. Another indicator is measuring the share of aromatic carbon.[4] Common to these indicators, however, is that they cannot reflect the decomposition processes the biochar is exposed to in the soil.

The methods that attempt to mimic these decomposition processes include incubation studies in which laboratory-produced biochar is mixed with soil samples and then subjected to certain thermal, chemical, or other treatments. Based on the incubation studies, which are usually of only short duration, conclusions can then be drawn for the long-term stability of biochar. The results of these studies point to the longevity of biochar. For example, mean residence times of at least 200 to 2,000 years were inferred for biochar in soils in temperate latitudes.[5]

Another approach is to measure the stability of historical biochar in its natural environment. The results for such naturally occurring biochar vary significantly. For instance, mean residence times between 718 and 9,259 years were calculated for biochar from vegetation fires in Australian soils.[6] In contrast, naturally occurring biochar in soils in Zimbabwe appears to survive only for decades to centuries,[7] while biochar in Kenya was found to have a mean residence time of only 8.3 years.[8] These mixed results indicate that the stability of biochar depends on many factors, not least on climatic conditions and other environmental influences. In addition, there are considerable difficulties and differences in determining the quantities of natural biochar present in soils.

Finally, the findings derived from Terra Preta studies suggest that biochar can be stored in the soil over a period of thousands of years. Radio carbon dating of biochar in certain European soils has produced similar results, with biochar ages ranging from 1,160 to 5,040 years.[9] In the case of these measurements, however, the amount of biochar that was originally added to the soil is unknown.

1 K.A. Spokas, "Review of the Stability of Biochar in Soils: Predictability of O:C Molar Ratios," Carbon Management 1, no.2 (2010): 289–303.

2 Enders et al., "Characterization of Biochars," 644–653.

3 O.R. Harvey, L. J. Kuo, A.R. Zimmerman, P. Louchouarn, J.E. Amonette, and B.E. Herbert, "An Index-Based Approach to Assessing Recalcitrance and Soil Carbon Sequestration Potential of Engineered Black Carbons (Biochars)," Environmental Science & Technology 46, no.3 (2012): 1415–1421.

4 For example K. Hammes, R.J. Smernik, J.O. Skjemstad, A. Herzog, U. F. Vogt, and M.W.I. Schmidt, "Synthesis and Characterisation of Laboratory-Charred Grass Straw (Oryza Sativa) and Chestnut Wood (Castanea Sativa) As Reference Materials for Black Carbon Quantification," Organic Geochemistry 37, no. 11 (2006): 1629–1633.

5 Kuzyakov et al. "Black Carbon Decomposition," 210–219.

6 J. Lehmann, J. Skjemstad, S. Sohi, J. Carter, M. Barson, P. Falloon, K. Coleman, P. Woodbury, and E. Krull, "Australian Climate-Carbon Cycle Feedback Reduced by Soil Black Carbon," Nature Geoscience 1 (2008): 832–835.

7 M.I. Bird, C. Moyo, E.M. Veenendaal, J. Lloyd, and P. Frost, "Stability of Elemental Carbon in a Savannah Soil," Global Biogeochemical Cycles 13, no.4 (1999): 923–932.

8 B. T. Nguyen J. Lehmann, J. Kinyangi, R. Smernik, S.J. Riha, and M.H. Engelhard, "Long-Term Black Carbon Dynamics in Cultivated Soil," Biogeochemistry 89, no.3 (2008): 295–308.

9 M.W.I. Schmidt, J.O. Skjemstad, and C. Jäger, "Carbon Isotope Geochemistry and Nanomorphlogy of Soil Black Carbon: Black Chernozemic Soils in Central Europe Originate From Ancient Biomass Burning," Global Biogeochemical Cycles 16, no.4 (2002): 70-1-70-8.

Table 1

Biomass and Biochar Potentials in Germany in 2030

	Feedstocks[2]	Biomass potentials: For energetic use	Biomass potentials: *Thereof: assumed use for biochar*	Biochar: Yield	Biochar: Carbon content	Biochar: Mass
		Thousand tonnes of dry matter per year		Percent		Thousand tonnes of dry matter per year
Solid biomass	Cereal straw	2,971	1,040	34	70	354
	Forestry residues	9,534	3,337	30	81	1,001
	Open-country biomass residues	1,264	442	31	69	137
	Industrial wood waste	3,098	1,084	29	82	314
	Wood in municipal solid waste[3]	1,225	429	30	81	129
	Green waste: Compensation areas	570	200	32	63	64
	Biomass: Habitat-connectivity areas	1,100	385	31	69	119
	Green waste: Extensive grassland	1,630	571	31	69	177
	Poplars and willows: Erosion areas	5,500	1,925	25	72	481
Digestable biomass	Sewage sludge	965	338	49	35	166
	Cattle manure	4,753	1,664	47	51	782
	Swine manure	1,276	447	47	49	210
	Poultry manure	814	285	44	46	125
	Liquid manure (cattle and swine)	8,967	3,138	45	44	1,412
	Crop residues (potato haulm and sugar-beet leaf)	884	309	45[1]	51[1]	139
	Commercial and industrial waste	595	208	37	66	77
	Organic municipal solid waste	2,296	804	45[1]	63	362
	Digestates from energy crops (corn)	3,589	2,692	49	42	1,319
	Total	**51,031**	**19,296**	–	–	**7,369**

1 Calculated as the average of the corresponding values for digestable biomass.
2 Selection according to J. Nitsch, et al. and U. R. Fritsche, et al.
3 Wood content collected separately.
Sources: Nitsch et al., "Ökologisch optimierter Ausbau"; Fritsche et al., "Stoffstromanalyse"; calculations by DIW Berlin.

The greatest biochar potentials are from liquid manure, digestates, and forestry residues.

approximately to the calorific value of hard coal.[25] Typical calorific values for HTC char are to be found between 20 MJ/kg and below 30 MJ/kg, but well above the calorific value of lignite.[26] However, also significantly lower calorific values are possible in general.

Irrespective of the intended use of the biochar itself, the bio-oils and gases generated as by-products of the biochar production process can also be used for energy generation. The bio-oils can be used as a valuable transport fuel after they have been converted to bio-diesel, for example.[27] Depending on the chosen conversion process, the gases consist primarily of carbon monoxide, carbon dioxide, hydrogen, methane, and other hydrocarbons. A mixture of carbon monoxide and hydrogen (synthesis gas), for example, can be used to generate heat and electricity or be converted into transport fuels.[28]

Potentials for the Use of Biochar in Agriculture as a Carbon Sink in Germany

Against the background of the German government's climate goals, it is important to determine biochar's potential contribution to climate protection. At DIW Berlin, the greenhouse gas mitigation potentials and costs of biochar in German agriculture have been calculated, taking account of the energetic use of the bio-oils and gases generated during biochar production.

25 P. Quicker, "Thermochemische Verfahren zur Erzeugung von Biokohle," in "Biokohle im Blick – Herstellung, Einsatz und Bewertung," eds. K. Fricke, C.-G. Bergs, C. Kammann, P. Quicker, and R. Wallmann, ORBIT (Weimar: 2012): 21–33.

26 Quicker, "Thermochemische Verfahren," 21-33.

27 R. Slade, R. Saunders, R. Gross, and A. Bauen, Energy From Biomass: The Size of the Global Resource, Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre (London: 2011).

28 Slade et al., Energy From Biomass.

Due to the importance of the initial biomass for the yield and properties of the biochar, the abatement opportunities and costs were differentiated according to the type of feedstock. The study considered only biochars produced in the slow pyrolysis process since they tend to be very stable in soil and since the carbon transfer from the biomass to the biochar is especially high.

Exemplifying the analysis, the following provides the results from a chosen scenario for 2030.[29] The reference is provided by a so-called baseline scenario, i.e. by assumptions about the conventional feedstock management if the biomass is not converted to biochar. Although the costs of carbon sequestration through biochar might be reduced by possible co-benefits in agriculture, these effects are not taken into account here.

Climate Protection Potential of Biochar Depends Largely on Availability of Biomass

Besides the choice of the baseline scenario and other assumptions, the greenhouse gas abatement potential of biochar depends largely on the assumed biomass potential available for biochar. In order to obtain a reasonably realistic estimate of the biomass potential for future biochar production in Germany, first, the calculations were based on the biomass potentials considered available for energy generation in the literature.[30] Then, assumptions were made as to how much of this potential could be used for biochar. Thereby, the focus was primarily on biomass residues. Digestates from biogas production were explicitly included in the analysis to take account of so-called cascade utilization in which a raw biomass material is first used to produce energy and then to produce biochar.[31]

Table 1 shows the biomass potentials the calculations for 2030 are based on. The chosen scenario assumes that there will be a relatively high availability of biomass for the production of biochar—35 percent of the energetic potential of solid and digestable biomass and 75 percent of the potentially available digestates from energy crops.[32] The table also shows the quantities of biochar that can be produced from this biomass. The largest quantities of biochar can be generated from liquid manure and digestates from energy crops, followed by forestry residues. In total, approximately 19 million tonnes of biomass (dry mass) are available in the chosen scenario. They can be turned into more than 7 million tonnes of biochar.

Based on assumptions in the literature, 68 percent[33] of the carbon in biochar made from solid biomass and 34 percent[34] of the carbon in biochar made from digestable biomass and digestates are considered to remain stable in the long term, that is, for at least 100 years. In addition to the carbon sequestration from adding biochar to the soil, the analysis also covers the avoided emissions of CO_2, methane (CH_4) and nitrous oxide (N_2O) caused by the shift from conventional feedstock management to biochar production. These include, for example, emissions from the conventional manure management or composting. The emissions avoided by substituting fossil fuels by the pyrolysis oils and gases are also taken into account. These vary depending on whether lignite, hard coal, or natural gas are replaced, and whether they are used for the production of heat or electricity.[35]

The production and use of biochar, however, also leads to some emissions, for example, caused by transporting the biomass and biochar between the pyrolysis plants and fields, by adding the biochar to the soil, and by soil processes. In addition, energy is required for drying the biomass and for the pyrolysis process itself. Since the demand for this energy is only generated by the biochar production, the study assumes that fossil energy sources will be used to cover this demand, thereby, causing greenhouse gas emissions.[36]

29 In the specific scenario, it is assumed that biochar is produced in medium-sized pyrolysis plants with an annual biomass capacity of 16,000 tonnes of dry matter. An upcoming DIW Discussion Paper includes a number of other scenarios up to 2050. The scenarios differ, in particular, according to the possible feedstock-specific biomass potential, the size of the pyrolysis plants, and the amount of biochar that is incorporated into the soil.

30 J. Nitsch, W. Krewitt, M. Nast, P. Viebahn, S. Gärtner, M. Pehnt, G. Reinhardt, R. Schmidt, A. Uihlein, K. Scheurlen, C. Barthel, M. Fischedick, and F. Merten, Ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland, Research Project on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, FKZ 901 41 803, long version (Stuttgart, Heidelberg, Wuppertal: 2004); and U. R. Fritsche, G. Dehoust, W. Jenseit, K. Hünecke, L. Rausch, D. Schüler, K. Wiegemann, A. Heinz, M. Hiebel, M. Ising, S. Kabasci, C. Unger, D. Thrän, N. Fröhlich, F. Scholwin, G. Reinhardt, S. Gärtner, A. Patyk, F. Baur, U. Bemmann, B. Groß, M. Heib, C. Ziegler, M. Flake, M. Schmehl, and S. Simon, Stoffstromanalyse zur nachhaltigen energetischen Nutzung von Biomasse, Joint Project supported by the BMU as part of ZIP, promoter: FZ Jülich, final report (Darmstadt, Berlin, Oberhausen, Leipzig, Heidelberg, Saarbrücken, Braunschweig, Munich: 2004).

31 Cp. J. Mumme, "HTC, Biogas und Landwirtschaft – das APECS-Konzept," in "Biokohle im Blick – Herstellung, Einsatz und Bewertung," eds. K. Fricke, C.-G. Bergs, C. Kammann, P. Quicker, and R. Wallmann, ORBIT (Weimar: 2012): 135.

32 An alternative scenario, not discussed in more detail here, is to first use the digestable biomass residues for biogas production and then to use the resulting digestate to make biochar.

33 S. Shackley, J. Hammond, J. Gaunt, and R. Ibarrola, "The Feasibility and Costs of Biochar Deployment in the UK," Carbon Management 2, no.3 (2011): 335–356.

34 Author's own assumptions based on the reduced stability of biochar with high ash content. Cp. A. Enders, K. Hanley, T. Whitman, S. Joseph, and J. Lehmann, "Characterization of Biochars to Evaluate Recalcitrance and Agronomic Performance," Bioresource Technology 114 (2012): 644–653.

35 For the case outlined here, it is assumed that the pyrolysis oils and gases replace hard coal in power generation.

36 It is assumed here that the heat required for the pyrolysis process (including drying the biomass) is derived from natural gas.

Table 2

Greenhouse Gas Mitigation Potentials and Costs of Biochar in Germany in 2030

	Feedstocks[2]	Baseline scenario	Mitigation potential		Mitigation costs
			Tonnes of CO_2 equivalents per tonne of biomass (dry mass)	Thousand tonnes of CO_2 equivalents	Euros per tonne of CO_2 equivalent
Solid biomass	Cereal straw	Decomposition in field	0.86	893	187
	Forestry residues	Decomposition in forest	0.93	3,088	256
	Open-country biomass residues	Composting, land spread	1.24	547	76
	Industrial wood waste	Energetic use	−0.19	−206	–
	Wood in municipal solid waste[3]	Composting, land spread	1.34	575	68
	Green waste: Compensation areas	Decomposition on site	0.76	152	367
	Biomass: Habitat-connectivity areas	Composting, land spread	1.24	476	76
	Green waste: Extensive grassland	Composting, land spread	1.24	707	76
	Poplars and willows: Erosion areas	Energetic use	−0.29	−566	–
Digestable biomass	Sewage sludge	Composting, land spread	0.04	12	4,044
	Cattle manure	Solid storage, land spread	0.54	897	220
	Swine manure	Solid storage, land spread	0.90	404	148
	Poultry manure	Solid storage, land spread	0.68	194	151
	Liquid manure (cattle and swine)	Liquid storage, land spread	−0.62	−1,960	–
	Crop residues (potato haulm and sugar-beet leaf)	Decomposition in field	−0.46	−143	–
	Commercial and industrial waste	Composting, land spread	0.92	192	119
	Organic municipal solid waste	Composting, land spread	0.46	371	277
	Digestates from energy crops (corn)	Composting, land spread	0.05	141	2,979
	Total	–	–	8,648[1]	–

1 Includes only positive abatement potentials.
2 Selection according to J. Nitsch, et al. and U. R. Fritsche, et al.
3 Wood content collected separately.
Source: calculations by DIW Berlin.

Greenhouse gas mitigation potentials and costs for the individual feedstocks vary widely.

Table 2 summarizes the greenhouse gas emissions that are sequestered or avoided by the use of biochar and of the pyrolysis oils and gases. In the example chosen here, they amount to approximately 8.6 million tonnes of CO2 equivalents in 2030. This potential corresponds to approximately 1.3 percent of the reduction target for 2030 of 678 million tonnes of CO2.[37] Thereby, the greatest greenhouse gas abatement potential is associated with biochar made from forestry residues, that is, from a relatively dry feedstock occurring in relatively large quantities.

The 8.6 million tonnes of CO2 do not include biochar produced from industrial wood waste, poplars and willows from erosion areas, liquid manure (cattle and swine) and crop residues (potato haulm and sugar-beet leaves), which result in positive greenhouse gas emissions. The reasons for the additional greenhouse gas emissions when using industrial wood waste as well as poplars and willows can be found in the chosen baseline scenario, which assumes that both feedstocks are used energetically. Replacing hard coal, the conventional feedstock management reduces greenhouse gas emissions considerably. If, instead, biochar is produced from these feedstocks, the emission reductions are comparatively low. For liquid manure and crop residues, in turn, the high emissions from drying these very wet feedstocks are crucial for the negative greenhouse gas balance.

Costs of Biochar Carbon Sequestration Vary Widely and Are Sometimes Substantial

Table 2 also contains the specific costs associated with the production of biochar and its addition to soil, as compared to the baseline scenario. The costs mainly consist of the investment and operating costs for the pyrolysis plants, the feedstock and transport costs for the biomass as well as the costs of transporting and storing the biochar and adding it to the soil. The items that have to be deducted from the costs include the revenues from providing the pyrolysis oils and gases for energy generation as well as the avoided costs associated with conventional feedstock management in the baseline scenario.

37 The 678 million tonnes of CO_2 are calculated based on the base year emissions in Germany of 1,232.4 million tonnes of CO_2 and the reduction target of 55 percent. See UNFCCC, Report of the Review of the Initial Report of Germany (2007).

Given the applied assumptions, the costs of greenhouse gas abatement in 2030 range from 68 euros per tonne of CO2 for wood in municipal solid waste to over 4,000 euros per tonne of CO2 for sewage sludge. The very high specific costs for sewage sludge and digestates from energy crops (corn) are caused by the very high water contents of these substrates.

Figure 3 summarizes the potentials and costs of carbon sequestration and greenhouse gas abatement from biochar in a so-called marginal abatement cost curve. Thereby, the possible measures for greenhouse gas abatement—based on the feedstocks used for the biochar—are first ordered by cost (lowest first). Then, the abatement potential (in millions of tonnes of CO2 equivalents) for each measure is plotted on the horizontal axis and the associated costs (in euros per tonne of avoided CO2 equivalent) are shown on the vertical axis. For a given level of greenhouse gas abatement, the curve shows the costs that would be incurred by an additional unit of greenhouse gas abatement—known as the marginal abatement costs. Consequently, the curve indicates which measures can most efficiently achieve a given greenhouse gas reduction target. At the same time, the curve shows the amount of greenhouse gas emissions that can be mitigated at a given carbon price—such as in an emissions trading system—when only taking into account greenhouse gas abatement measures with costs at or below the carbon price.

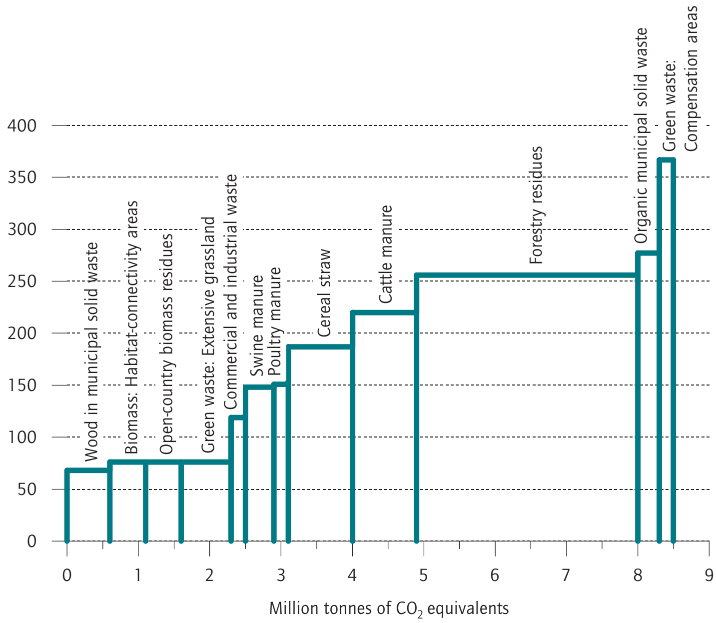
As shown in Figure 3, only approximately 2.3 million tonnes of greenhouse gases can be mitigated with the help of biochar in 2030 at a cost below 100 euros per tonne of CO2 equivalent, i.e. only about 0.3 percent of the reduction target for 2030. This refers to biochar made of the following feedstocks: wood in municipal solid waste, biomass from habitat-connectivity areas, open-country biomass residues, and green waste from extensive grassland.

The calculated values are comparable to the results obtained from a similar study for the UK.[38] The study finds that – depending on the assumed biomass potential – approximately one to six million tonnes of CO2 can be mitigated annually by using biochar in British agriculture; however, at a price of just 29 US dollars per tonne of CO2 (based on 2007 prices) or approximately 21 euros per tonne of CO2.[39]

Figure 3

Marginal Abatement Cost Curve[1] of Possible Biochar Options in Germany in 2030

Euros per tonne of CO_2 equivalent



1 Only options with abatement costs of less than 400 euros per tonne of CO_2 equivalent are shown. Thus, biochars from sewage sludge and from digestates from energy crops (corn) are not shown. In addition, options resulting in negative emission abatement are not included (industrial wood waste, poplars and willows, liquid manure, and crop residues).

Source: calculations by DIW Berlin.

About 2.3 million tonnes of CO_2 can be mitigated at a cost of less than 100 euros per tonne of CO_2 equivalent.

A comparison of biochar with other greenhouse gas abatement measures does not permit any general conclusions. Compared to the broad-scale implementation of CCS in the energy sector—which is, however, unrealistic from today's perspective[40]—the greenhouse gas abatement potential of biochar appears low and its costs seem high. For 2030, McKinsey & Co. arrived at a mitigation potential of 66 million tonnes of CO2 through CCS, at a cost of 30 to 90 euros per tonne of CO2.[41] In the same study, an abatement potential of nine million tonnes of CO2 was assumed for the energetic use of biomass—for 2020, however—whereby the cost was generally less than 30 euros per tonne of CO2. Finally, for certain biofuels, the costs of greenhouse gas abatement were estimated to reach 190 to 240 euros per tonne of

38 Shackley et al., "The Feasibility and Costs of Biochar," 335–356.

39 The conversion was based on the average 2007 exchange rate of 1.3705 US dollars to 1 euro. See Deutsche Bundesbank, Euro Reference Exchange Rates of the European Central Bank: End-of-Year Rates and Annual Averages, exchange rate statistics as of Dec 31, 2012.

40 See von Hirschhausen et al. "CCTS-Technologie ein Fehlschlag."

41 McKinsey & Company, Costs and Potentials of Greenhouse Gas Abatement in Germany, a report by McKinsey & Company, Inc., on behalf of "BDI initiativ – Business for Climate."

CO_2 by 2020, with a low abatement potential of approximately one million tonnes of CO_2.

The greenhouse gas abatement potential and costs of biochar strongly depend on the assumptions made about future developments. These include, in particular, the chosen baseline scenario, the fossil fuels used for biomass drying and pyrolysis, the fossil fuels replaced by the pyrolysis oils and gases, as well as the size and distribution of the pyrolysis plants. Following a change in the set of assumptions, further cost reductions and/or increases in the greenhouse gas abatement potential may be possible.

Conclusion

Biochar is produced by heating biomass in the near absence of oxygen. It is characterized by a high and stable carbon content as well as large nutrient-retention and water-holding capacities. These properties render biochar very attractive for an application in agriculture. By incorporating biochar into soils, carbon dioxide can be removed from the atmosphere for long time scales. At the same time, soil fertility can be increased.

Given it will be possible in the future to precisely quantify how much carbon can be stored long-term in soil using biochar, the use of biochar in German agriculture seems a possible option for climate protection, which could complement other greenhouse gas mitigation measures. Based on the sample calculation presented in this report, approximately 1.3 percent of the German greenhouse gas reduction target for 2030 could be achieved through the use of biochar in agriculture, approximately 0.3 percent at costs below 100 euros per tonne of CO_2.

The specific greenhouse gas abatement potentials and associated costs depend on the chosen scenario assumptions, in particular on the biomass potential considered available for biochar. Thereby, competition with food production and energy generation for the use of biomass must also be taken into account, but cannot be studied in more detail in a scenario-based analysis like this. In addition, future research will reveal to what extent possible agricultural co-benefits of biochar in the form of enhanced soil fertility will improve biochar's greenhouse abatement potential and costs.

In other climate regions, the assessment of biochar might differ from that in Germany. Particularly in the tropics and subtropics, which typically have severely degraded soils, biochar might significantly improve soil quality. This is also supported by the example of Terra Preta.

While the present analysis has focused on the soil incorporation of biochar, its use in generating energy should be studied in more detail. In particular, the use of wet biomass residues in the HTC process to produce biochar for generating energy may prove to be an efficient alternative. Optimized combinations of feedstock types, biochar production processes and biochar use can be expected to increase the areas of biochar application and to reduce its costs.

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JEL: Q15, Q24, Q54
Keywords: Biochar, soil carbon sequestration, climate change, agriculture

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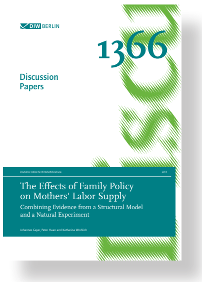

The Effects of Family Policy on Mothers' Labor Supply: Combining Evidence from a Structural Model and a Natural Experiment

Parental leave and subsidized child care are prominent examples of family policies supporting the reconciliation of family life and labor market careers for mothers. In this paper, we combine different empirical strategies to evaluate the employment effects of these policies for mothers in Germany. In particular we estimate a structural labor supply model and exploit a natural experiment, i.e. the reform of parental leave benefits. By exploiting and combining the advantages of the different methods, i.e the internal validity of the natural experiment and the external validity of the structural model, we can go beyond evaluation studies restricted to one particular methodology. Our findings suggest that a combination of parental leave benefits and subsidized child care leads to sizable employment effects of mothers.

JEL-Classification:J22, H31, C52
Keywords:Labor supply, parental leave benefits, childcare costs, structural model, natural experiment
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Turning Back to Turkey - or Turning the Back to Germany?: Remigration Intentions and Behavior of Turkish Immigrants in Germany between 1984 and 2011

By applying event-history analysis to all available waves of the German Socio-Economic Panel, we analyze how remigration intentions and actual remigration of Turkish migrants to Germany have evolved over time. The study draws from a broad set of theoretical approaches to remigration and it takes a different focus than previous studies by concentrating on long-term change in these rates. Our findings reveal an increase in remigration intentions and rates for first generation migrants after the turn of the millennium. Those who plan to return have a stronger emotional attachment to Turkey than those who plan to stay. Nevertheless, the two groups differ neither with respect to their educational levels nor in terms of their identification with Germany and perceptions of discrimination. Similarly, the small though slightly increasing group of immigrants that actually returns does not have a clear profile in terms of educational level, national identification, and perceptions of being disadvantaged in Germany. We thus argue that for first-generation migrants from Turkey after 2001, rising remigration intentions and actual remigration are unrelated to their integration into German society. Rather, the increase seems to be triggered by macro-structural changes in the country of origin.

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