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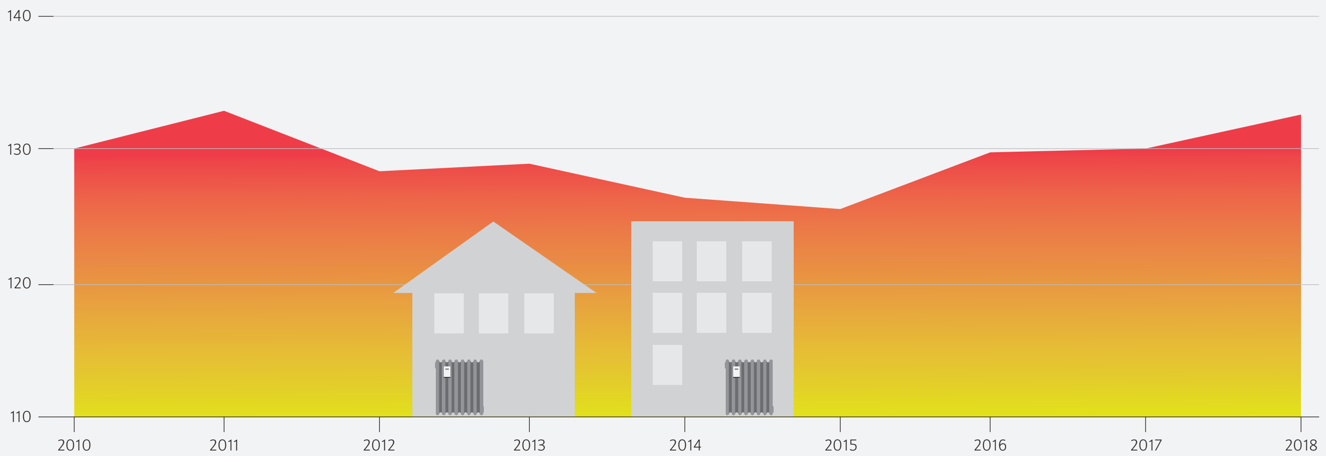
AT A GLANCE

Heat Monitor 2018: Rising heating energy demand, thermal retrofit rate must increase

By Puja Singhal and Jan Stede

- Heating energy demanded by residential buildings continues to increase
- Large increase in heating oil prices in 2018
- Differences in heating energy demand between East Germany and West Germany persist
- Higher rate of thermal retrofitting in the 1990s shows potential for more upgrades
- Policymakers should strengthen efforts to realize energy savings in the building sector

Lost decade in the building sector; heating energy demand in multi-family homes in 2018 surpasses 2010 demand
Kilowatt hours per square meter heated living space



Source: ista Deutschland GmbH, authors' own calculations.

FROM THE AUTHORS

"The low retrofit rate shows that we are far away from achieving the goal of significantly reducing energy consumption in the buildings sector. Existing policies do not have enough impact."

— Jan Stede —

MEDIA

Audio Interview with Jan Stede (in German)
www.diw.de/mediathek

Heat Monitor 2018: Rising heating energy demand, thermal retrofit rate must increase

By Puja Singhal and Jan Stede

ABSTRACT

Residential heating accounts for almost one-fifth of Germany's final energy consumption. This report evaluates an extensive database of heating bills for buildings with two or more apartments, representing more than two-thirds of the total housing stock in Germany. Despite commitments to pressing climate targets, the rate of thermal upgrades of the existing housing stock has remained low since the turn of the 21st century, while heating energy demanded per square meter by private households has been on an upward trend since 2015. This is an alarming development with respect to the 2050 climate goals for the buildings sector. An additional set of policies are therefore necessary to achieve the yet-unrealized reductions in energy consumption in the building sector. These include, for example, tax incentives for top-end retrofits that have been discussed for more than a decade and policies targeting household behavior such as providing consumers with more frequent and timely information.

Residential heating accounts for almost one-fifth of Germany's final energy consumption.[1] The German government plans to make the buildings sector "almost climate-neutral" by 2050.[2] More than 80 percent of the final energy use of private households comes from heating living space and water.[3] This makes policies addressing heating energy consumption central to achieving that target. The German Federal government's primary aim has been to improve the thermal performance of the existing housing stock. To achieve this goal, the leading policy instruments include: (1) mandatory thermal standards (*Energieeinsparverordnung* or EnEV) for retrofits since 2002, (2) providing financial incentives (loans or grants) to encourage energy-efficient renovations by homeowners via the German Development Bank (KfW), and (3) backing up these regulations by advocating that thermal upgrades achieving the mandatory standards pay back in the long run.[4] The investment level to modernize the housing stock, however, has remained extremely low. Even though the volume of refurbishments efforts has been steadily increasing, expenditures for energy efficiency renovations declined in 2018 (Figure 1).[5]

1 See Federal Ministry for Economic Affairs and Energy, "Zahlen und Fakten, Energiedaten," (Berlin: BMWi, 2019) (in German, available online; accessed on July 31, 2019; this applies to all other online sources in this report unless stated otherwise) and AG Energiebilanzen e.V., "Anwendungsbilanzen für die Endenergiesektoren in Deutschland in den Jahren 2013 bis 2017," (Berlin: AGEB, 2018) (in German, available online).

2 Federal Ministry for Economic Affairs and Energy, "Energy Efficiency Strategy for Buildings. Methods for achieving a virtually climate-neutral building stock" (Berlin: BMWi, 2015) (available online).

3 In 2017, heating space and heating water accounted for 68.8 and 15.3 respectively of the final energy demanded by households. By sector, households used about a quarter of the final energy consumed overall in Germany. See Federal Ministry for Economic Affairs and Energy, "Zahlen und Fakten, Energiedaten," 2019.

4 Starting with the EnEV 2002, there also exists a clause, according to which a homeowner, carrying out upgrades, has the possibility to apply for an exemption if the standards could be proven economically unviable. See Ray Galvin and Minna Sunikka-Blank, A Critical Appraisal of Germany's Thermal Retrofit Policy – Turning Down the Heat (London: Springer-Verlag, 2013).

5 Measures involving products such as insulation (roof, facade, etc.), replacing windows and outer doors, heating system renewal and solar thermal energy/photovoltaics are all considered energy efficiency upgrades. See Martin Gornig et al., "Strukturdaten zur Produktion und Beschäftigung im Baugewerbe – Berechnungen für das Jahr 2018." Gutachten im Auftrag des Bundesministeriums für Inneres, für Bau und Heimat (BMI) sowie des Bundesinstituts für Bau-, Stadt- und Raumforschung (BBSR). Endbericht. German Institute for Economic Research, Berlin, 2019 (in German; forthcoming).

DOI: https://doi.org/10.18723/diw_dwr:2019-XX-X

The 2018 *Heat Monitor* assesses the energy used for space heating by German residential buildings with two or more apartments – nearly 70 percent of the total housing stock[6] (Box 1). The main goal of this annual report is to describe trends in residential heating energy demand, and to evaluate heating costs paid by residential consumers with centralized natural gas or oil heating systems. Additionally, for the first time, the 2018 *Heat Monitor* also shows the long-term development of a thermal retrofit rate for the building sample served by *ista Deutschland*.[7] This rate indicates the area share of the building envelope of an average building that received an energetic modernization during any given year (Box 2).

Energy requirement increases yet again

Heating energy demand per square meter, adjusted for changes in climate and weather, increased by two percent in buildings with two or more apartments in 2018 relative to the previous year. This was the third consecutive increase in the energy demand (Figure 2). From the point of view of reducing energy required by the German building sector, the period since 2010 increasingly looks like a "lost decade" and the 20 percent heating energy reduction target is out of sight.[8]

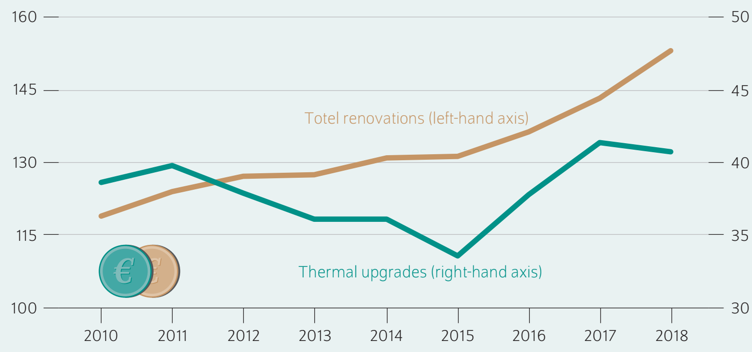
Strong regional differences in terms of heating energy demanded persist between East and West Germany as well as on the *Bundesland* level. In 2018, households in West Germany required seven percent more per square meter than households in East Germany (Figure 3). The East-West gap in energy demand continues to persist, but the gap has closed significantly since heating requirements fell at a faster rate in West Germany compared to East Germany in the early 2000s. One factor explaining the trends could be the differences in retrofit rates observed between the East and the West over time (discussed below):[9] Households in East Germany were gaining from a stronger wave of thermal renovations in the late 90s[10] while comparatively, West Germany has benefited more since the mid-2000s.

Heating energy demand in 2018 was highest in the Schleswig-Holstein Süd-West region and lowest in the Mecklenburg/Rostock region. However, there is no strict East-West divide; the West German region Allgäu and the city of Munich, for example, have the second-lowest and third-lowest per-square meter heating requirement of all German regions (Table).

Figure 1

Volume of renovations of existing residential buildings

Billion euros in current prices



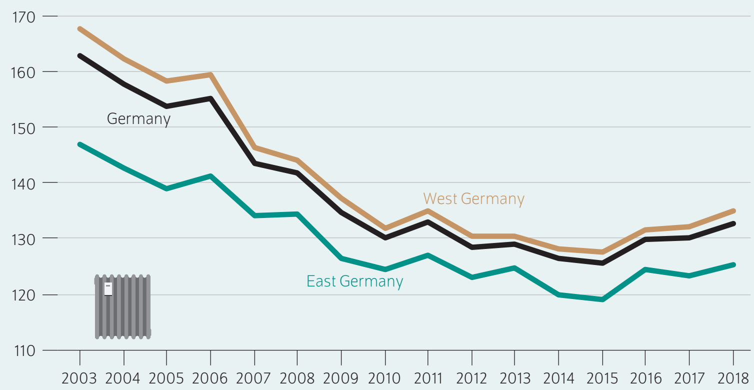
Source: Construction volume calculation by DIW Berlin.

Expenditures on energy efficiency renovations declined in 2018 in contrast to the steadily increasing total refurbishment efforts.

Figure 2

Heating energy demand in two or more apartment buildings

Annual heating energy demand in kilowatt hour per square meter heated living space; adjusted for climate and weather



Source: ista Deutschland GmbH, authors' own calculations.

Heating energy demanded per square meter by private households has been on an upward trend since 2015.

6 German Federal Statistical Office, "Bauen und Wohnen. Mikrozensus – Zusatzerhebung 2014." Fachserie 5 Heft 1, Statistisches Bundesamt, Wiesbaden, 2016 (in German; available online).

7 ista Deutschland GmbH is an energy metering service provider that also issues heating bills for a large share of German residential consumers.

8 Jan Stede, Claus Michelsen and Puja Singhal, "Wärmemonitor 2017: Heizenergieverbrauch stagniert, Klimaziel wird verfehlt," DIW Wochenbericht, no. 39 (2018): 833 (in German; available online).

9 However, thermal retrofits (or the energy efficiency of a building) are not the only reason why households adjust their energy demand. Other factors such as energy prices and household demographics (like income) also play an important role. See Ray Galvin and Minna Sunikka-Blank, Turning Down the Heat, 103–114.

10 See also Claus Michelsen and Nolan Ritter, "2016 Heat Monitor: 'Second Rent' Lower Despite Higher Heating Energy Consumption," DIW Weekly Report, no. 38 (2017): 378 (available online).

Box 1

Database und methodology used for Heat Monitor 2018

In partnership with *ista Deutschland GmbH*, one of the largest energy service providers in Germany, the DIW Berlin has developed the *Heat Monitor Germany*. The Monitor reports regional and national trends in heating energy consumption and heating costs for residential buildings annually. The calculations are based on (1) building-level heating bills from *ista Deutschland GmbH*, (2) climate adjustment factors from the German Weather Service (*Deutscher Wetterdienst*), and (3) census survey results from the German Federal Statistical Office. The heating bills contain information on energy consumption, billing periods, heating fuel type, energy costs, and building location and size.

The heating bills capture residential buildings with two or more apartments – i.e., the sample covers occupied buildings, owned or rented, with at least two households. We further limit the sample of buildings to those with heated living space of between 15 and 250 square meters per apartment. Note that we do not have a random sample from the population of residential buildings in Germany. In comparison with the 2014 microcensus supplementary survey,[1] buildings with three to six apartments and larger buildings (13 or more apartments) are overrepresented in the sample. We offset this by weighting average heating consumption according to the relative importance of each building size category in the statistical population. To accomplish this, we use results from the 2010 microcensus supplementary survey that indicate the shares of each building size category by planning region (ROR).

For each building, we calculate heating demand by adjusting total energy consumed for heating for local changes in the climate and weather. To ensure comparability across time and space, we use information from the German Weather Service. The available weighting factors normalizes heating consumption to climatic condition in Potsdam, the reference location.[2]

We calculate the annual quantity of heating energy demand in relation to the heated living space of a building. This is carried out in several steps: First, building-specific consumption values are limited to the amounts of energy used for heating space (excluding warm water). Second, the consumption value is multiplied by the heating value corresponding to the building's energy fuel type, giving us the absolute heating energy consumption in kilowatt-hours (kWh) for a building in a billing period. Third, the values are allocated to a specific heating year, since the closing date for measurement is not always December 31 of the relevant year. Fourth, we adjust the consumption values for the climatic conditions during the heating period in question and divide it by the amount of heating space in the building. The units are kilowatt-hours required per square meter of heated living space per year (kWh/sqm). We drop implausible values of heating energy demand – above 400 or below 30 kWh/sqm of heated living space – about four percent of the observations each billing year.

Lastly, average heating demand values at the planning region level are computed as the weighted arithmetic mean for the overall building stock of a planning region – for weights, we use the proportion of buildings in each housing size category (two, three to six, seven to 12, 13 to 20, and over 21 apartments) at the planning region level.

Heating bills are created with a time lag. The values of the 2018 heating period are calculated based on a smaller sample than the values for earlier years. Therefore updates would likely lead to corrections in the future.

We calculate heating costs using costs per kWh of heating energy consumed (excluding heating water). Only the amounts billed for natural gas and heating oil are included. District heating, electric heating systems, biomass, or other heating types are not considered. The average price per kWh for a planning region is calculated as a weighted average value, weighting by the share of buildings by heating type (natural gas or oil) in the statistical population as reported by the 2010 microcensus supplementary survey.

In previous *Heat Monitors*, the statistics were calculated using data on buildings with three or more apartments - i.e. only multi-family apartment buildings. The 2018 *Heat Monitor* reports results for a larger building stock and is thus not directly comparable to previous editions.

1 German Federal Statistical Office, „Bauen und Wohnen. Mikrozensus - Zusatzerhebung 2014." Fachserie 5 Heft 1, Statistisches Bundesamt, Wiesbaden, 2016 (in German; available online).

2 Our procedure follows an established method developed by the Association of German Engineers (*Verein Deutscher Ingenieure*, VDI): VDI Guideline 3807, "Characteristic consumption values for buildings").

Heating oil prices rise significantly

Overall median oil and gas prices that residential consumers paid per kWh for their heating bills remained flat in 2018 (Figure 4). However, there are regional differences. On the one hand, prices in Schleswig-Holstein Nord rose by more than seven percent compared to 2017. On the other hand, prices in Oldenburg decreased by more than seven percent. The price levels are also quite different. While in the Saar region consumers paid almost six cents per kilowatt-hour in 2018, it was only 4.5 cents in Prignitz-Oberhavel and Munich (Table).

The development of consumer prices for natural gas versus heating oil prices was very different in 2018. While prices for natural gas stagnated (-0.3 percent relative to the previous year), oil prices soared by more than 20 percent (Figure 5). However, changes in consumer prices for oil only translate into changes in heating costs with a time lag. Since heating oil is often "bunkered," there is a time lag between the rise of market prices and the actual heating costs paid by consumers[11]. Heating costs for multi-family homes using heating oil increased by only nine percent in 2018, while costs billed for gas heating decreased by around four percent.

Roughly, half of German homes are heated with natural gas while another quarter uses heating oil.[12] Expenditures for heating homes have increased by two percent in 2018 (Figure 6). This results due to the combination of stagnant energy prices and an increase in energy demanded per square meter. However, price increases were higher for households that use heating oil, since oil prices have soared.

Retrofit rate in East Germany has dropped drastically since the 1990s

To achieve the climate targets in the building sector, the German federal government had planned to double the rate of thermal renovation from one to two percent. [13] However, there is surprisingly little consensus on how this thermal retrofit rate (also called "renovation rate") should be calculated methodologically, nor is there any long-term evidence on the development of the retrofit rate for Germany.[14]

11 See Stede, Michelsen and Singhal, "Wärmemonitor 2017," 835: (in German; available online)

12 Stede, Michelsen and Singhal, "Wärmemonitor 2017," 835: (in German; available online)

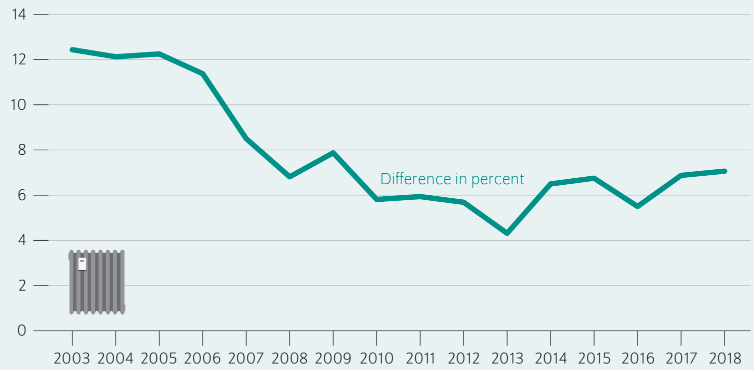
13 Federal Ministry for Economic Affairs and Energy and Federal Ministry for the Environment, "Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung," (PDF, Federal Ministry for Economic Affairs and Energy, Berlin, 2010).

14 There are two studies calculating a retrofit rate for a representative sample of German residential buildings for the years 2005–2008 and 2010–2016, respectively. The average retrofit rate is based on the individual rates of the building components façade, roof/top floor ceiling, cellar, and windows. See Holger Cischinsky and Nikolaus Diefenbach, Datenerhebung Wohngebäudebestand 2016 (Darmstadt: IWU, 2018) (in German; available online) and Nikolaus Diefenbach et al., Datenbasis Gebäudebestand (Darmstadt: IWU/BEI, 2010) (in German; available online). Other authors have calculated a retrofit rate based on the labelling steps of energy performance certificates, see Filippidou et al., "Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database", Energy Policy 109 (2017): 488–498. On a European level, Article 5 of the EU Energy Efficiency Directive (Directive 2012/27/EU) obligates Member States to retrofit buildings representing three percent of the total floor area of all government buildings each year. After the renovations, buildings must meet the minimum energy performance requirements of the Energy Performance of Buildings Directive (Directive 2010/31/EU).

Figure 3

Difference in heating energy requirements between East and West Germany in percent

Annual heating energy demand in kilowatt hour per square meter heated living space; adjusted for climate and weather



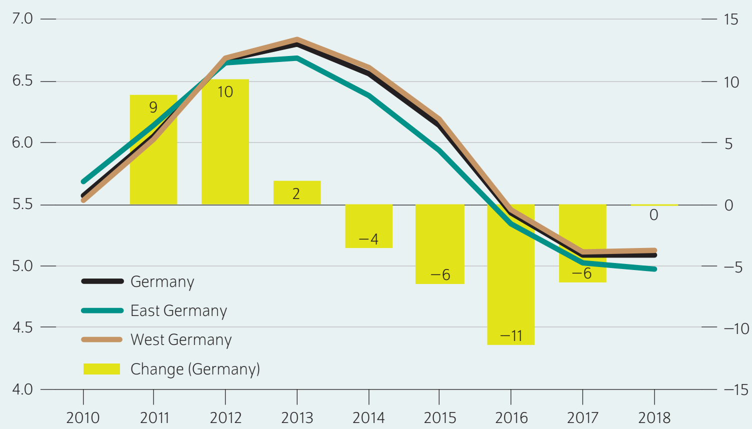
Source: ista Deutschland GmbH, authors' own calculations.

West Germany requires more heating energy than East Germany. In 2018, it required seven percent more.

Figure 4

Energy prices

Weighted median of natural gas and oil prices in euro cents per kilowatt hour (left axis), change in percent (right axis)



Source: ista Deutschland GmbH, authors' own calculations.

Energy prices faced by households were constant in 2018, in contrast to the continuous decline observed since 2014.

Box 2

Calculation of a thermal retrofit rate

The estimated annual retrofit rate indicates the share of all building surfaces that are retrofitted in a given year. It is a weighted average of energetic retrofit rates computed for each building component: façade, roof/top floor ceiling, cellar ceiling, and windows. The weights reflect the share of the total surface of a typical residential building attributed to each component.[1] Additionally, the rates for each of these components account for the share of the surface that is insulated on average, such as the fraction of windows that is replaced during a typical retrofit.[2]

We calculate the retrofit rate based on a subsample (henceforth EPC sample) of the full sample used for the *Heat Monitor*. The EPC sample covers more than 100,000 buildings for which *ista Deutschland GmbH* issued energy performance certificates (EPCs) according to the requirements of the *Energieeinsparverordnung*. Owners that sell or rent a building or flat in Germany have to provide such energy performance certificates to the potential buyer or tenant upon request for all buildings since January 2009.[3] EPCs include information on the year of the latest energetic retrofit of façade, roof, top floor ceiling, cellar, and windows, as well as the year of construction or modernization of the heating system. This information is provided by the building owners upon application for an energy performance certificate. Here, applicants are asked to state the last time a component of a building was thermally retrofitted, e.g. by insulating the façade (but excluding non-energetic refurbishments such as painting the façade).[4]

One caveat of the calculation is that for every EPC we only observe the most recent thermal upgrade for each building component. For many buildings in the EPC sample we only have information from one energy performance certificate on the retrofits in that building. Consequently, we may be underestimating the retrofit rate in the case that buildings have been retrofitted more than once. Our estimates should therefore be seen as a lower bound to the true retrofit rate, especially for the period of the 1990s. For some of the buildings, however, we have information from more than one EPC.[5] These buildings are included in the retrofit rate if they were already retrofitted in the past and some of their components are re-insulated.[6]

National trends of energy demanded per square meter for the EPC sample are almost identical to that of the full sample. Furthermore, the regional distribution (state-wise) of the buildings observed in the EPC sample is very close to the regional distribution of the actual German residential buildings in the microcensus supplementary survey.[7] However, the EPC subsample has a higher proportion of larger buildings (more than seven flats per building) than the full sample and is therefore not representative of the entire German residential building stock.

1 The weights used for the different components are 40 percent for the façade, 28 percent for the roof/top floor ceiling, 23 percent for the cellar and 9 percent for windows. Modernizations of the heating system are not included in the retrofit rate. For an overview of the methodology to calculate the weights, see Cischinsky and Diefenbach, Datenerhebung Wohngebäudebestand 2016 and Nikolaus Diefenbach and Tobias Loga, eds., "Application of Building Typologies for Modelling the Energy Balance of the Residential Building Stock". TABULA Thematic Report No. 2 (2012). Darmstadt (available online).

2 This share varies significantly by component. While it is high for façade, roof/top floor ceiling, and cellar (75 percent, 90.4 percent and 80.3 percent, respectively), only 54.6 percent of windows are replaced in a typical retrofit. See Cischinsky and Diefenbach, Datenerhebung Wohngebäudebestand 2016.

3 This legislation applies to both new buildings and the existing building stock. See Deutscher Bundesrat, "Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung – EnEV)" (2007). Bundesrats-Drucksache 282/07 (27.04.07). The Energieeinsparverordnung 2014 (EnEV 2014) has introduced the additional requirement that key information from the energy performance certificate has to be included by default in advertisements for the sale or renting out of a building.

4 When information on the retrofit status of a component of any given building is missing, this building is not included in the calculation of the retrofit rate for that specific component (e.g., the rate for energetic modernisation of windows). When the year indicated as the retrofit year of any component equals the construction year of a building, we assume that no retrofit has taken place for that specific component. This might lead to an underestimation of the retrofit rate.

5 The energy performance certificates in our sample were issued mostly between 2008 and 2018. EPCs have to be renewed every ten years in order to comply with the Energieeinsparverordnung.

6 This applies to less than 100 of all buildings in our sample. For each component of these buildings, we assume that retrofits can only take place every five years.

7 See German Federal Statistical Office, "Mikrozensus – Zusatzerhebung 2014."

We calculate an annual retrofit rate based on the share of the building envelope of an average building that is covered by thermal retrofits of different building components, such as the façade, roof, or windows, for a subsample of more than 100,000 German buildings (Box 2). Although this subsample is not representative for the entire German building stock, the retrofit rate from our sample is similar to the rate calculated for a representative sample of German buildings using the same methodology.[15]

The annual retrofit rate has mostly remained below one percent in the last 15 years, although it has picked up since the early 2000s (Figure 7). Rates for West Germany have been higher than in East Germany since 2006. Compared to today's comparably low efforts, however, major renovations in Germany took place in the 1990s in East Germany. The average retrofit rate for the East German buildings in our sample rose to more than three percent after the reunification (between 1993 and 2000), peaking at values of close to four percent in 1995 and 1996.

Conclusion: Broader set of energy-saving policies necessary for the buildings sector

After a gradual decline until 2015, dropping by almost 23 percent relative to 2003 levels, heating energy demand in German residential buildings is on an upward trend. Temperature-adjusted heating energy demand has picked up and is now almost six percent above 2015 levels. This is an alarming development, which policymakers should take note.

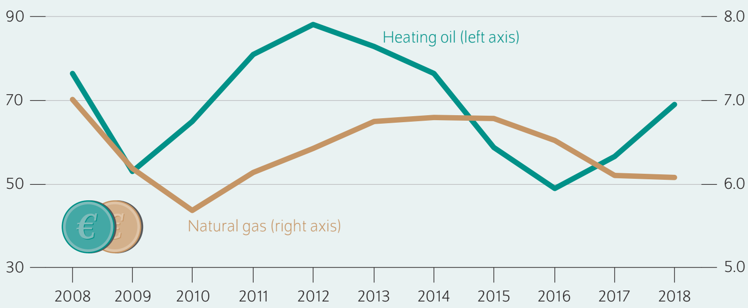
The 2018 *Heat Monitor* shows that the average rate of thermal retrofits was significantly higher in the 1990s for East Germany, while the average retrofit rate for West Germany did not exceed 0.5 percent. Nationally, the retrofit rate for the buildings was below one percent in the last 15 years. This means that on average less than one percent of the total building surface of buildings, served by *ista Deutschland*, received an energetic modernization. If trends are similar for Germany nationally, this will not suffice to tap the vast potential of energy efficiency programs in the buildings sector.

Additional sets of policies are necessary to achieve the yet-unrealized reductions in energy required by the building sector in Germany.[16] These include tax incentives for top-end retrofits that have been discussed for more than a decade and policies targeting household behavior such as providing

Figure 5

Development of consumer prices for heating oil and natural gas

Costs in cent per liter heating oil; cent per kilowatt hour natural gas



Source: Eurostat, Mineralölbundesverband.

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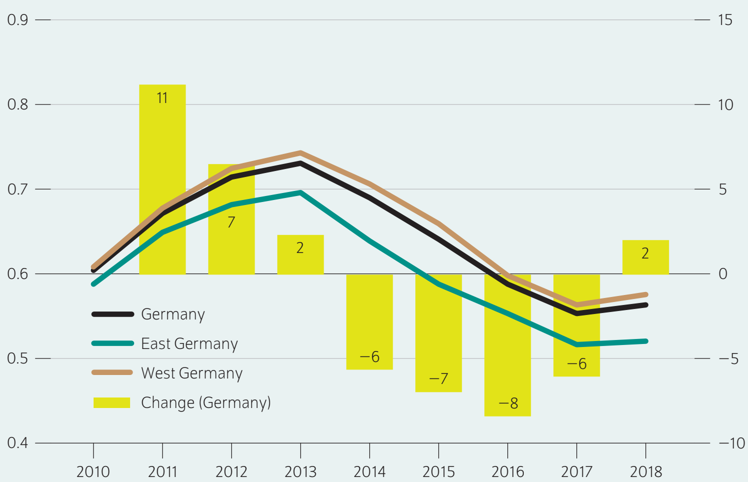
After having fallen for years, consumer prices for heating oil have increased for the second year in a row.

Figure 6

Monthly heating expenditures

In euros per square meter heated living space (left axis), change in percent (right axis)



Source: ista Deutschland GmbH, authors' own calculations.

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In the last year, expenditures on heating fuel rose for the first time since 2014.

15 For the years 2010–2016, Cischinsky and Diefenbach, Datenerhebung Wohngebäudebestand 2016 find an average retrofit rate of 0.99 percent for the entire residential building stock, and a rate of 1.43 percent for buildings built until 1978. Using the same same methodology as Cischinsky and Diefenbach, we obtain an overall yearly retrofit rate of 0.90 percent and a rate of 1.33 for old buildings in the same period. In their 2010 study, using a similar methodology, the authors calculate an annual retrofit rate of 0.8 percent for all buildings and 1.1 percent for old buildings for the years 2005 to 2008 (Nikolaus Diefenbach et al., Datenbasis Gebäudebestand, 12). For the same years, in our sample we compute rates of 0.64 percent and 1.02 percent, respectively. Consequently, the rates we calculate are about 10 percent lower.

16 For a critical and extended discussion of various measures that could contribute to climate goals in the housing sector, see Ray Galvin and Minna Sunikka-Blank, Turning Down the Heat, 103–114.

Table

Results of Heat Monitor 2018

Spatial planning region	Number of ROR (2009)	Annual heating energy demand (kilowatt hour per square meter heated living space), Average			Billed heating costs (euro cents per kilowatt hour), Median			Annual heating expenditure (euros per square meter), Average		
		2016	2017	2018[1]	2016	2017	2018[1]	2016	2017	2018[1]
Schleswig-Holstein Mitte	101	134.86	137.24	137.65	5.41	5.19	5.28	7.29	7.12	7.27
Schleswig-Holstein Nord	102	131.47	133.50	136.10	5.29	5.11	5.49	6.96	6.83	7.48
Schleswig-Holstein Ost	103	143.24	141.31	142.72	5.42	4.87	4.96	7.77	6.89	7.08
Schleswig-Holstein Süd	104	140.84	143.83	145.87	5.18	4.86	5.01	7.29	7.00	7.31
Schleswig-Holstein Süd-West	105	155.81	166.48	167.29	5.03	4.67	4.62	7.84	7.77	7.74
Hamburg	201	147.20	150.72	150.17	5.04	4.94	5.04	7.41	7.45	7.56
Braunschweig	301	126.69	128.26	127.30	5.50	5.24	5.20	6.97	6.72	6.62
Bremen-Umland	302	149.35	149.68	150.89	5.36	5.00	5.02	8.01	7.49	7.57
Bremerhaven	303	152.90	152.07	152.73	5.22	4.98	4.94	7.98	7.57	7.54
Emsland	304	148.38	149.18	158.79	5.24	4.86	4.81	7.77	7.24	7.64
Göttingen	305	125.12	127.29	132.78	5.44	5.09	5.03	6.80	6.48	6.68
Hamburg-Umland-Süd	306	142.88	143.55	140.70	4.97	4.64	4.75	7.11	6.65	6.68
Hannover	307	128.55	129.82	130.22	5.55	5.36	5.27	7.13	6.96	6.87
Hildesheim	308	133.76	134.33	131.52	5.47	5.16	5.15	7.31	6.93	6.77
Lüneburg	309	143.87	144.29	144.25	5.14	4.76	4.79	7.40	6.88	6.90
Oldenburg	310	150.97	153.16	153.64	5.36	4.98	4.61	8.09	7.62	7.08
Osnabrück	311	130.92	132.10	134.67	5.43	5.10	5.08	7.11	6.73	6.84
Ost-Friesland	312	158.62	159.52	161.09	5.52	5.09	4.81	8.75	8.12	7.74
Südheide	313	146.11	146.43	147.34	5.13	4.92	5.14	7.50	7.21	7.58
Bremen	401	143.67	147.51	143.50	5.52	5.20	5.05	7.93	7.67	7.25
Aachen	501	137.02	138.11	142.02	5.99	5.75	5.70	8.21	7.94	8.10
Arnsberg	502	129.45	130.61	135.73	5.52	5.13	5.17	7.15	6.70	7.02
Bielefeld	503	142.14	142.96	145.02	5.55	5.24	5.26	7.89	7.50	7.63
Bochum/Hagen	504	139.93	140.73	144.58	5.89	5.51	5.54	8.24	7.76	8.01
Bonn	505	144.29	145.04	149.45	5.86	5.49	5.47	8.45	7.97	8.18
Dortmund	506	139.28	140.45	141.27	5.74	5.37	5.28	7.99	7.54	7.45
Duisburg/Essen	507	141.00	141.38	142.74	5.99	5.73	5.67	8.45	8.10	8.09
Düsseldorf	508	145.00	145.94	147.52	5.63	5.37	5.35	8.16	7.83	7.89
Emscher-Lippe	509	132.99	134.09	133.30	6.24	5.85	5.67	8.30	7.84	7.56
Köln	510	140.48	140.66	143.93	5.52	5.19	5.18	7.75	7.30	7.46
Münster	511	132.13	132.40	134.67	5.16	4.76	4.74	6.81	6.30	6.39
Paderborn	512	126.96	131.25	134.89	5.90	5.49	5.49	7.50	7.21	7.41
Siegen	513	133.82	139.34	141.18	5.60	5.25	5.35	7.49	7.32	7.55
Mittelhessen	601	129.00	130.29	133.51	5.46	5.10	5.20	7.04	6.64	6.95
Nordhessen	602	127.20	128.65	129.96	5.42	5.14	5.31	6.90	6.61	6.89
Osthessen	603	114.43	116.43	121.24	5.31	4.88	5.03	6.08	5.68	6.10
Rhein-Main	604	134.41	133.05	135.86	5.30	4.87	4.81	7.13	6.47	6.54
Starkenburg	605	142.25	142.11	148.35	5.60	5.22	5.16	7.96	7.42	7.66
Mittelrhein-Westerwald	701	134.68	135.46	139.69	5.76	5.48	5.55	7.75	7.42	7.75
Rheinhessen-Nahe	702	140.02	141.63	143.86	5.63	5.32	5.21	7.88	7.54	7.49
Rheinpfalz	703	140.48	140.01	147.03	5.56	5.16	4.99	7.81	7.23	7.34
Trier	704	134.82	138.13	139.16	5.69	5.52	5.68	7.67	7.62	7.90
Westpfalz	705	141.22	139.53	148.81	5.73	5.46	5.40	8.10	7.61	8.04
Bodensee-Oberschwaben	801	114.60	113.82	119.71	5.42	4.91	4.93	6.21	5.59	5.90
Donau-Iller (BW)	802	115.88	117.61	121.66	5.54	5.07	5.08	6.41	5.97	6.18
Franken	803	123.62	120.98	123.53	5.49	4.96	5.00	6.79	6.00	6.17
Hochrhein-Bodensee	804	122.76	123.96	130.20	5.25	4.92	4.81	6.44	6.10	6.26
Mittlerer Oberrhein	805	128.86	127.29	133.48	5.40	5.03	5.06	6.96	6.40	6.75
Neckar-Alb	806	119.87	120.89	122.78	5.45	5.00	5.15	6.54	6.05	6.33
Nordschwarzwald	807	113.93	115.87	119.71	5.44	5.06	5.19	6.20	5.86	6.21
Ostwürttemberg	808	125.29	126.30	132.20	5.37	4.90	5.04	6.73	6.19	6.66
Schwarzwald-Baar-Heuberg	809	109.26	109.16	109.57	5.56	5.00	4.99	6.07	5.46	5.47
Stuttgart	810	125.89	125.90	129.28	5.35	4.89	4.92	6.73	6.15	6.36
Südlicher Oberrhein	811	114.61	114.10	120.15	5.33	4.89	4.85	6.11	5.58	5.83
Unterer Neckar	812	132.27	131.80	135.14	5.73	5.33	5.23	7.58	7.02	7.07
Allgäu	901	101.64	101.02	106.30	5.17	4.74	4.81	5.25	4.78	5.11
Augsburg	902	119.92	118.76	121.92	4.92	4.57	4.61	5.90	5.42	5.62
Bayerischer Untermain	903	135.82	138.36	131.13	5.19	4.77	4.77	7.04	6.60	6.25
Donau-Iller (BY)	904	117.39	117.80	124.12	5.25	4.85	4.80	6.16	5.71	5.96
Donau-Wald	905	113.64	116.93	119.96	5.25	4.94	5.10	5.96	5.78	6.12

Table (continued)

Results of Heat Monitor 2018

Spatial planning region	Number of ROR (2009)	Annual heating energy demand (kilowatt hour per square meter heated living space), Average			Billed heating costs (euro cents per kilowatt hour), Median			Annual heating expenditure (euros per square meter), Average		
		2016	2017	2018[1]	2016	2017	2018[1]	2016	2017	2018[1]
Industrieregion Mittelfranken	906	123.70	124.81	128.79	5.32	4.89	4.97	6.58	6.11	6.40
Ingolstadt	907	115.68	115.20	122.31	5.06	4.72	4.86	5.85	5.44	5.95
Landshut	908	110.84	113.17	116.94	5.13	4.82	4.92	5.69	5.45	5.75
Main-Rhön	909	122.45	124.30	127.01	5.47	4.99	5.03	6.70	6.21	6.39
München	910	105.98	105.45	109.65	4.87	4.41	4.54	5.16	4.65	4.97
Oberfranken-Ost	911	118.22	120.82	121.60	5.34	5.09	5.18	6.31	6.15	6.29
Oberfranken-West	912	118.97	121.88	129.02	5.36	5.00	5.15	6.38	6.09	6.65
Oberland	913	106.60	105.67	111.80	5.05	4.66	4.79	5.39	4.93	5.36
Oberpfalz-Nord	914	123.09	122.20	117.83	5.33	5.09	5.18	6.56	6.22	6.10
Regensburg	915	116.99	117.28	118.31	5.22	4.93	5.08	6.11	5.79	6.00
Südostoberbayern	916	111.04	114.50	116.64	5.14	4.82	4.92	5.71	5.51	5.74
Westmittelfranken	917	124.17	124.83	126.49	5.43	4.98	5.16	6.74	6.22	6.53
Würzburg	918	122.02	123.02	125.84	5.43	4.92	4.89	6.63	6.05	6.15
Saar	1001	147.15	146.76	155.51	5.99	5.77	5.90	8.82	8.47	9.18
Berlin	1101	136.23	135.64	135.26	5.13	4.90	4.95	6.99	6.65	6.69
Havelland-Fläming	1201	126.99	125.84	129.48	5.38	4.82	4.74	6.83	6.07	6.13
Lausitz-Spreewald	1202	126.97	122.89	130.76	5.44	5.17	4.91	6.91	6.35	6.43
Oderland-Spree	1203	130.20	127.42	131.06	5.40	5.08	5.05	7.03	6.47	6.61
Prignitz-Oberhavel	1204	136.07	134.89	143.59	5.28	4.67	4.50	7.18	6.30	6.46
Uckermark-Barnim	1205	125.28	126.42	132.81	5.42	5.20	4.99	6.79	6.57	6.63
Mecklenburgische Seenplatte	1301	118.58	123.80	123.90	5.82	5.63	5.69	6.90	6.97	7.05
Mittleres Mecklenburg/Rostock	1302	101.52	97.61	97.68	5.03	4.80	4.79	5.10	4.68	4.68
Vorpommern	1303	111.24	110.73	112.70	5.39	5.14	5.09	5.99	5.69	5.74
Westmecklenburg	1304	114.96	118.27	114.04	5.70	5.31	5.14	6.55	6.28	5.86
Oberes Elbtal/Osterzgebirge	1401	113.57	112.86	116.58	5.16	4.72	4.63	5.86	5.33	5.40
Oberlausitz-Niederschlesien	1402	124.13	122.73	129.09	5.47	5.01	4.94	6.79	6.14	6.38
Südsachsen	1403	117.79	117.11	118.79	5.35	5.08	4.95	6.30	5.95	5.88
Westsachsen	1404	115.98	112.19	117.94	5.54	5.05	5.04	6.43	5.66	5.94
Altmark	1501	137.47	128.50	127.83	5.79	5.52	5.54	7.96	7.09	7.09
Anhalt-Bitterfeld-Wittenberg	1502	129.55	128.83	127.85	5.43	5.20	5.26	7.04	6.70	6.72
Halle/S.	1503	123.75	124.38	131.51	5.55	5.24	5.27	6.86	6.52	6.93
Magdeburg	1504	127.00	126.02	128.44	5.89	5.49	5.38	7.48	6.91	6.91
Mittelthüringen	1601	112.87	113.96	115.30	5.24	4.81	4.68	5.92	5.48	5.39
Nordthüringen	1602	119.83	116.36	117.20	5.39	5.22	5.08	6.46	6.07	5.95
Ostthüringen	1603	119.32	111.68	117.29	5.39	5.10	5.03	6.43	5.69	5.90
Südthüringen	1604	119.07	121.39	120.80	5.38	5.09	5.02	6.41	6.18	6.06
Federal State										
Schleswig-Holstein	1	139.2	141.4	142.9	5.30	4.98	5.13	7.37	7.05	7.33
Hamburg	2	147.2	150.7	150.2	5.04	4.94	5.04	7.41	7.45	7.56
Lower Saxony	3	136.0	137.1	138.0	5.41	5.12	5.06	7.36	7.02	6.98
Bremen	4	143.7	147.5	143.5	5.52	5.20	5.05	7.93	7.67	7.25
Northrhein-Westfalia	5	139.6	140.5	142.8	5.73	5.41	5.38	8.00	7.60	7.68
Hesse	6	133.0	132.8	136.1	5.39	4.99	5.00	7.17	6.63	6.81
Rheinland-Palatinate	7	138.2	138.8	143.6	5.67	5.37	5.34	7.84	7.46	7.66
Baden-Wuerttemberg	8	122.9	122.7	126.9	5.43	4.99	5.00	6.67	6.12	6.34
Bavaria	9	114.8	115.5	118.7	5.14	4.74	4.84	5.90	5.48	5.74
Saarland	10	147.1	146.8	155.5	5.99	5.77	5.90	8.82	8.47	9.18
Berlin	11	136.2	135.6	135.3	5.13	4.90	4.95	6.99	6.65	6.69
Brandenburg	12	128.6	126.6	132.4	5.39	4.98	4.83	6.93	6.31	6.40
Mecklenburg-Western-Pomerania	13	110.8	111.4	110.9	5.45	5.18	5.13	6.04	5.77	5.69
Saxony	14	117.0	115.5	119.2	5.36	4.97	4.89	6.27	5.74	5.83
Saxony-Anhalt	15	127.1	126.1	129.4	5.68	5.35	5.33	7.22	6.75	6.90
Thuringia	16	117.3	115.0	117.3	5.34	5.02	4.92	6.26	5.78	5.77
Germany		**129.83**	**130.13**	**132.75**	**5.43**	**5.09**	**5.09**	**7.05**	**6.63**	**6.76**
East Germany		**124.32**	**123.16**	**125.42**	**5.35**	**5.03**	**4.98**	**6.65**	**6.19**	**6.24**
West Germany		**131.51**	**132.24**	**134.97**	**5.46**	**5.11**	**5.12**	**7.18**	**6.76**	**6.92**

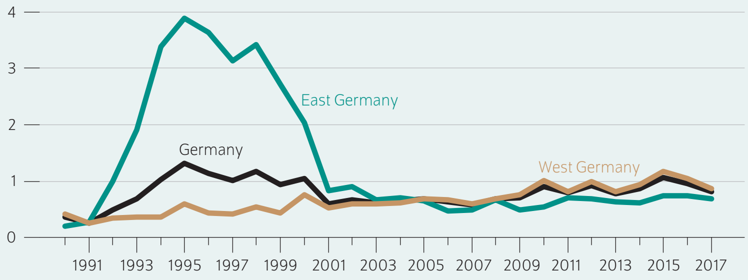
1 Preliminary. Notes: Heating energy use is adjusted for changes in the climate and weather to give heating demand; billed heating costs are a weighted average of natural gas and oil prices; for some regions, values have been substantially revised compared to the publication from last year.

Source: ista Deutschland GmbH, authors' own calculations.

Figure 7

Thermal retrofit rate

Area share of the total building envelope of an average building that receives an energetic modernisation, in percent



Source: ista Deutschland GmbH, authors' own calculations.

After major retrofits in East Germany in the 1990s, the retrofit rate has remained below one percent in the last 15 years.

consumers with more frequent and timely information[17]. As of today, Germany is not on a pathway towards reaching its 2050 climate goals for the buildings sector.

17 See Rupert Pritzl, "Warum die steuerliche Förderung der energetischen Gebäudesanierung in Deutschland nicht kommt – eine institutionenökonomische Betrachtung," Zeitschrift für Energiewirtschaft, vol. 43, no. 1 (2018): 39–49 (in German).

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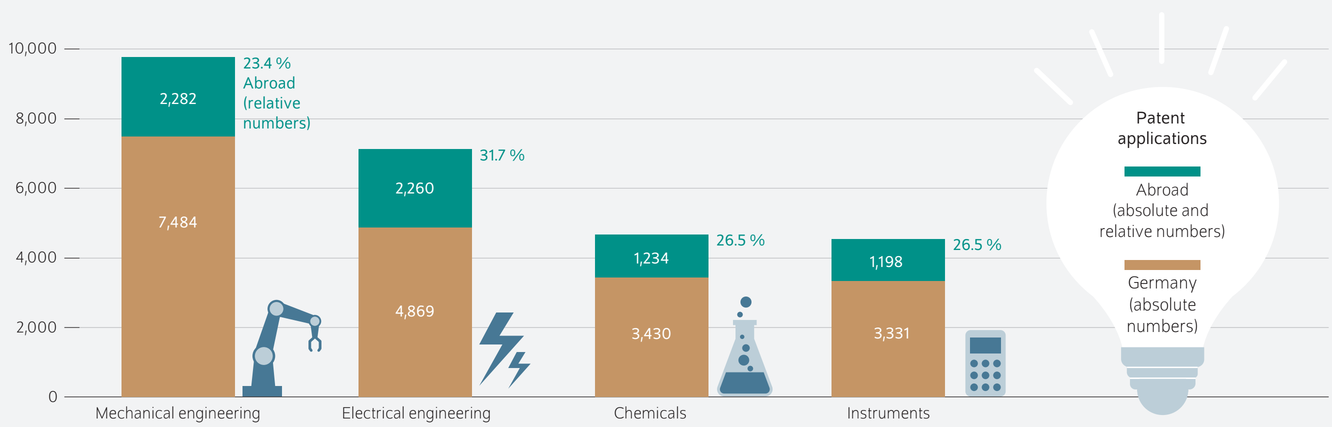
AT A GLANCE

Research and development abroad: German companies focus on strengths similar to those at home

By Heike Belitz, Anna Lejpras, and Maximilian Priem

- Based on patent data, the study examined the extent and orientation of German companies' R&D activities abroad
- More than one in four patents that German companies apply for is based on inventions from their research laboratories abroad
- In most cases, companies' activities abroad supplement and enhance the knowledge they acquired at home; supporting market development is a second motive
- Germany does not sacrifice its own importance as a research location due to the international R&D activities of German companies; no indication of "relocation"
- However, deficits in new digitalization technologies must increasingly be compensated for abroad; research in this field should be strengthened in Germany

German companies' foreign R&D focuses on technological areas in which they make many inventions domestically



Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

FROM THE AUTHORS

"The performance of domestic R&D still largely determines the innovative strength of German companies operating globally. Germany is not losing any importance as a research location as a result of international activities; although relocation is a fear, there are hardly any indications of it occurring."
— Heike Belitz —

DATA

Data on the **104 companies strongest in research in Germany** and on 1,564 competitors worldwide were evaluated.

Research and development abroad: German companies focus on strengths similar to those at home

By Heike Belitz, Anna Lejpras, and Maximilian Priem

ABSTRACT

More than one in four patents that major German companies apply for is based on inventions from their research laboratories abroad. In three quarters of the cases, the companies have focused on technologies in which they are very strong at home. Therefore, to a great extent the technological research and development performance at their home location determines the innovative power of globally active German companies. As the present report also shows, based on patent data, most foreign research activities abroad either supplement domestic activities or support sales and production abroad. Internationalization strategies intended to compensate for technological deficits at home have a lower proportion. German companies in the information and communication technology industries, whose importance is increasing in the wake of digitalization, are the primary implementers of such strategies. To better be able to acquire and use the knowledge companies gain abroad, the research in these technological fields of the future should be strengthened in Germany as well. As a research location, Germany can benefit from the continuing internationalization of its globally active companies if public research, at universities for example, can expand their technological basis and remain attractive cooperation partners to said companies.

When German companies carry out research and development (R&D) abroad, many interpret it as a loss for the domestic location.[1] From the company's point of view, it is useful to develop their products and processes further in foreign target markets, adapting them to local conditions and customer requirements. Setting up company research laboratories abroad can also serve the purpose of studying the new technological knowledge of local competitors, universities, and research institutes, or developing new products and processes in the local laboratory. After all, acquiring the know-how of research personnel in the host country is a key motive for R&D abroad.[2]

The German Institute for Economic Research (DIW Berlin) and DIW Econ[3] studied the scope and technological orientation of the R&D activities of German companies at home and abroad for the Hans Böckler Foundation.[4] For 104 top German R&D investing companies information on the focal areas of technological research they carry out at home and in various host countries abroad was acquired from patent data. The study encompassed the period from 2012 until 2014 (see Box 1). The technological and regional distribution of the R&D activities of German companies at home and abroad provides an indication of the motives for their internationalization. Was it driven by the desire to acquire new technological knowledge or by customer requirements

1 For example, Peter Bofinger, a member of the German Council of Economic Experts, described examples of German companies such as Siemens, Bosch, and Schaeffler setting up application-oriented research facilities in China as relocation. He views their activity as confirmation of the hypothesis according to which companies relocate their R&D activities to countries that can offer better R&D infrastructures and more beneficial financial support. See German Council of Economic Experts, "Setting the Right Course for Economic Policy," *Annual Report 2018/2019*, 79 (2018) (available online, accessed August 21, 2019; this applies to all other online sources in this report unless stated otherwise)

2 Among others, see Walter Kuemmerle, "Building effective R&D capabilities abroad," *Harvard Business Review*, March–April, (1997): 61–70; Parimal Patel and Modesto Vega, "Patterns of internationalisation of corporate technology: location vs. home country advantages," *Research Policy*, 28, (1999): 145–155; United Nations Conference on Trade and Development, World Investment Report: Transnational corporations and the internationalisation of R&D (2005) (available online); and Organisation for Economic Co-operation and Development, The Internationalisation of Business R&D: Evidence, Impacts and Implications (2008).

3 DIW Econ is the DIW Berlin subsidiary for economic consulting.

4 Heike Belitz, Anna Lejpras, Anselm Mattes and Maximilian Priem, "Forschung deutscher Unternehmen im In- und Ausland, Technologische Schwerpunkte und Zielregionen," *Working Paper der Forschungsförderung der Hans-Böckler-Stiftung*, 156, (2019) (available online).

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and conditions in the target market? Are the companies enhancing their knowledge abroad in the technologies in which they have a domestic advantage in their research laboratories? Or are they involved with technologies they need to catch up on, and as a result, have to carry out research at foreign locations?

Every fourth inventor for German companies works abroad

Among the 2,000 companies strongest in research worldwide in the period from 2012 until 2014, there are 114 German companies. They are responsible for 11 percent of global R&D expenditure. In 2014, that amounted to a solid 62 billion euros, approximately as much as the total R&D expenditure of all companies in Germany.[5] A total of 1,668 of the companies that are worldwide research leaders applied for patents. Among them were 104 companies from Germany, with a share of eight percent in all patents.

The foreign proportion of inventions by German companies was 27 percent during the study horizon of 2012-2014 (see Table 1). Around one in four inventors from German companies works abroad. The foreign proportion of R&D expenditure was 31 percent in 2013.[6] Thus, R&D carried out abroad leads to patents to the same extent as R&D done in Germany does. And the originality and quality of corporate research abroad are not significantly lower than that of the research done in Germany.

Altogether, the research-intensive industries transport equipment, mechanical engineering, data processing, electronics, optics, as well as the chemical and pharmaceutical industries are responsible for three quarters of the total worldwide inventions of German companies. German companies in the transport equipment industry have registered the most inventions (29 percent), followed by mechanical engineering (around 19 percent), data processing, electronics, and optics (12 percent, see Table 1). While transport equipment companies only developed one in five inventions abroad, the pharmaceutical industry's proportion is 36 percent.

Box 1

Data

For the company-specific analysis of worldwide R&D and patent activities of the 104 German research leaders by technological field and target country, two data sets were combined.

One data set contains information on the R&D expenditure and patent applications of the 2,000 global research leaders between 2012 and 2014 (EC-JRC/OECD COR&DIP© database, v.1. 2017 of the EC-JRC Institute for Prospective Technological Studies and the OECD Directorate for Science, Technology and Innovation), and the other is the

Patent database of the European Patent Office with bibliographical data on patents (EPO Worldwide Patent Statistical Database PATSTAT, spring 2018).

To avoid double counting inventions with multiple patent applications at multiple patent offices, the evaluation was carried out on the "patent family" level. Here, patent families summarize an invention's various patent applications to the world's five largest patent offices. The technological orientation of the R&D activities that support the invention was mapped based on 35 technological fields.[1] The place of invention for a patent family is equal to the inventor's place of residence. Since one invention mapped in a patent family can be allocated to several inventors at different places, several patents, several applying companies, and several technological fields, the patent families were weighted using a fractional counting method.

1 Ulrich Schmoch, "Concept of a Technology Classification for Country Comparisons. Final Report to the World Intellectual Property Organisation (WIPO)," 2008.

These inventions are concentrated in only a few companies. Only six large companies applied for one half of all patents of the 104 German companies, and among those with inventors abroad the proportion jumps to 60 percent (see Table 2). Among the six top patenting German companies, the share of inventions developed abroad varies greatly. At 44 percent, Infineon has the largest share of foreign inventions and at 19 percent, the share at Volkswagen is less than half of the size.

This is also a function of the different proportion of foreign invention in individual technological fields, which varies between 15 percent in handling and logistics and 48 percent in data processing. Some technological fields that have only minor importance to the German research leaders have particularly high proportions of foreign invention, including: IT methods for management, basic communication technology, biotechnology, food chemistry, and biological materials analysis (see Figure 1).

U.S., Austria, and France are the most important foreign research locations

Inventors in companies headquartered in Germany are located worldwide and are little regionally concentrated. Their distribution among the host countries is an approximate reflection of the distribution of R&D expenditures

5 The R&D expenditure of all companies in Germany (internal and external R&D expenditure outside the economic sector) was just under 67 billion euros in 2015. See SV Wissenschaftsstatistik, ɑːr ən ˈdiː: Zahlenwerk 2017, Forschung und Entwicklung in der Wirtschaft 2015, (2017).

6 See SV Wissenschaftsstatistik, ɑːr ən ˈdiː: Zahlenwerk 2015, Forschung und Entwicklung in der Wirtschaft 2013, (2015).

Table 1

Worldwide R&D expenditures and patent applications of German companies for industries, 2012 to 2014
Percentage shares

	R&D expenditure	Weighted patent applications	Foreign share
Manufacturing	86.5	88.7	–
Thereunder from:			
Chemical Industry	5.9	9.8	29
Pharmaceutical industry	13.9	5.4	36
Rubber, plastics, minerals	3.6	4.9	36
Computers, electronics, optics	3.2	12.2	32
Electrical equipment	1.6	3.3	24
Mechanical engineering	10.0	18.5	30
Transport equipment	45.7	29.2	20
Other industries	13.5	11.3	–
Thereunder from:			
Wholesale, retail, repairs	2.2	3.0	16
Professional, scientific, and technical activities	2.5	5.2	29
Total	100.0	100.0	27

Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

Table 2

Patent applications of the six top patenting German companies at home and abroad, 2012 to 2014
In percent

	Weighted patent applications of German companies			
Company	Worldwide	In Germany	Abroad	Foreign share
Bosch	17.2	17.9	15.4	23.8
Siemens	11.6	9.6	17.2	39.3
Infineon	7.2	5.5	12.0	44.2
Volkswagen	7.2	7.9	5.2	19.3
Continental	4.8	4.1	6.5	36.4
BASF	4.2	3.5	6.1	39.0
Total	52.2	48.5	62.4	–

Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

abroad.[7] The two key research regions for German companies abroad are the European Union and the U.S., with proportions of worldwide inventions of 12 and nine percent respectively between 2012 and 2014 (see Figure 2). By a clear margin, Asia comes next (five percent). In Europe, neighbors Austria at 3.4 percent and France at 1.8 percent are the largest host countries for the R&D of German companies. At 1.5 percent, China ranks number four. India and Eastern European countries, which have at times been reputed to be important locations for German companies, have very small proportions of patent applications.

In the technological categories of electrical engineering and mechanical engineering, the EU is the most important foreign research region, followed by the U.S. (see Figure 3). They are also the world's key location for R&D in chemical technology. In Asia, R&D activity in the field of electrical engineering clearly predominates.

Similar technological specialization at home and abroad

To find out the technological fields in which the companies have strengths and weaknesses, a revealed technological advantage index (RTA) was calculated using patent data (see Box 2). According to the RTA, in comparison to their competitors, globally active German companies are specialized in the "classic German" technological fields, which include

7 For 17 host countries for the R&D of German companies, primarily in Europe, the national statistics also contain information on the companies from Germany in the country. With a correlation coefficient of 0.984, the correlation between the R&D expenditure in 2015 and the weighted inventions of German companies in the period between 2012 and 2014 in those countries is very close. See Belitz, Lejpras, Mattes and Priem, "Forschung deutscher Unternehmen im In- und Ausland."

mechanical engineering (of which automotive engineering is a part), chemicals, and pharmaceuticals. On the contrary, in the entire area of electrical engineering, which includes information and communication technology, they are at a specialization disadvantage (see Figure 4).

Whether at home or abroad, German companies generally concentrate on the same technological fields. The relatively small fields of biotechnology and food chemistry are exceptions in which German companies only specialize abroad. They are at a specialization disadvantage in Germany in basic communication technology and IT methods for management, but this disappears when looking at research abroad.

Patent information can be used to examine which strategies German companies follow with their R&D activities abroad. In other words, it is possible to find out whether or not they research the technologies in which the host countries have technological advantages: in a global comparison, those in which they are highly specialized. This would indicate that in these countries, German companies are primarily searching for technological knowledge that is not available to them at home. If, on the other hand, they research in technological fields in which the host countries are not specialized (in which they do not have a distinct knowledge base), we can conclude that they are driven by market-related motives.

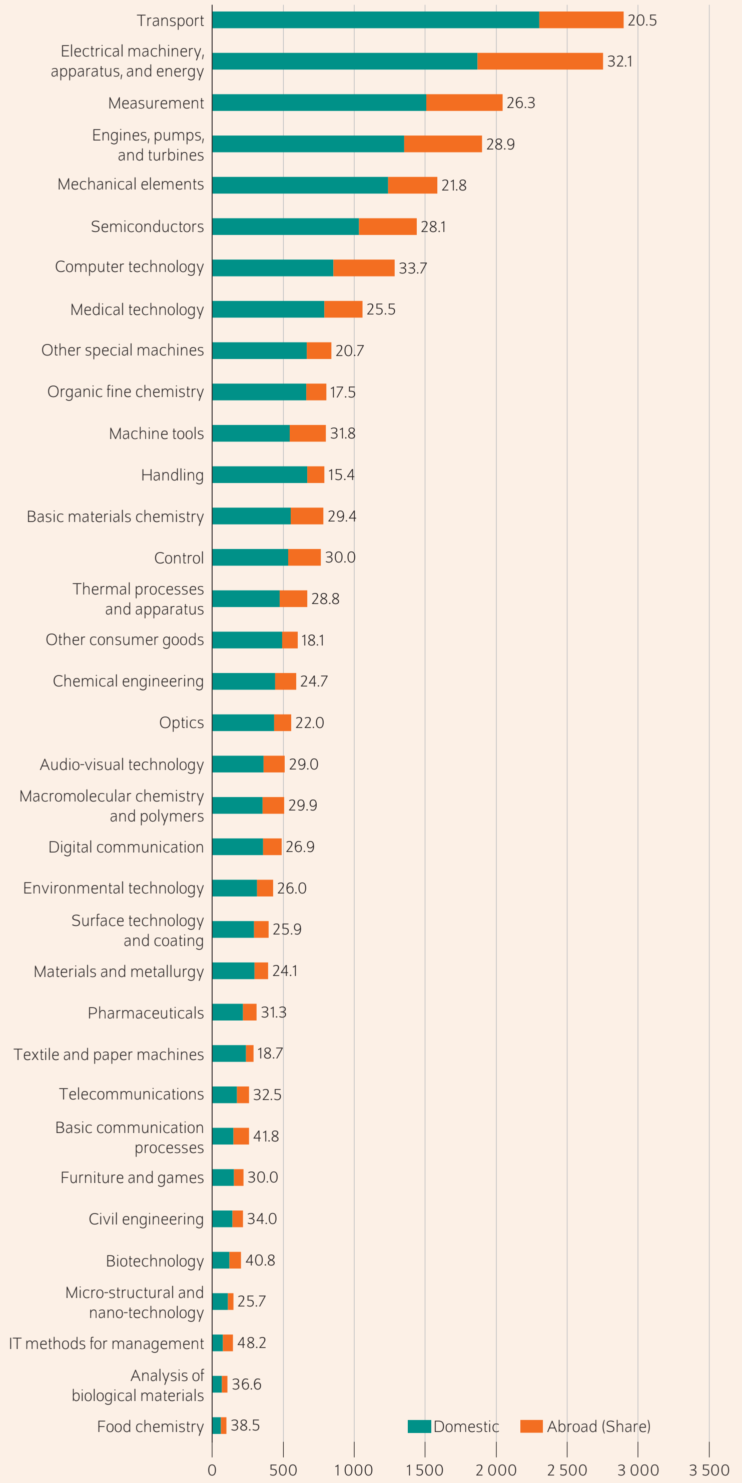
To characterize the internationalization strategy of German companies by technology and host country, we used the same classification scheme that the patent portfolios of the companies use. It has also been applied several times in the literature.[8] The strategies of the companies in the respective target region were identified based on two measures of technological advantage (see Box 2).

In order to determine the level of *a company's technological advantage in its home country (RTA home)*, we found the relationship between two proportions, first, the proportion of a company's patent applications that were researched abroad in relation to all of the company's patent applications and second, the proportion of all patent applications from companies in this technological field in relation to all patents worldwide.

In order to determine the level of *a company's technological advantage in its host country or region (RTA host)*, we also found the relationship between two proportions, first, the proportion of all patent applications of all companies that research in a specific technological field in relation to all patent applications in the host country and second, the proportion of patents applied for worldwide in this technological field in relation to all patents.

Figure 1

Patent applications of German companies at home and abroad by technological fields, 2012 to 2014



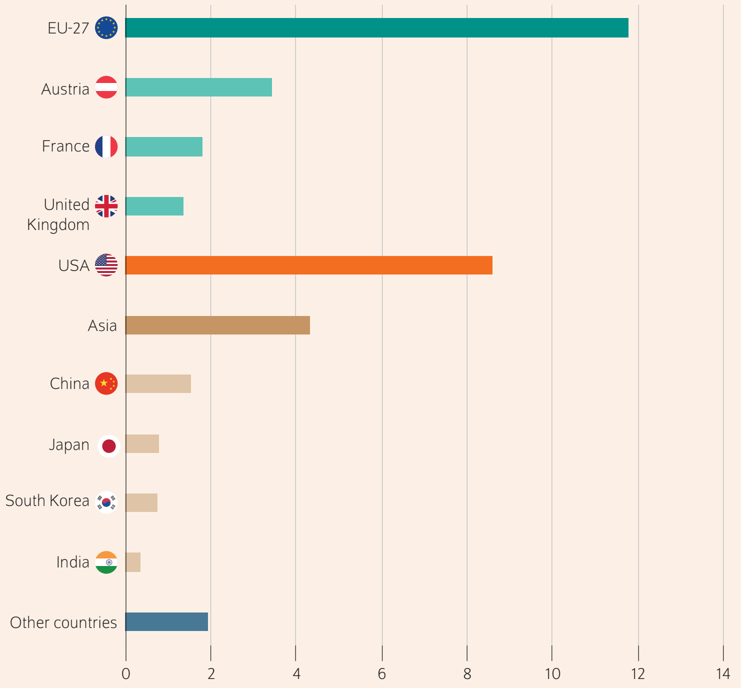
Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

Over all technological fields, the foreign share of inventions varies between 15 percent in handling and 48 percent in IT methods for management.

8 See Parimal Patel and Modesto Vega,"Patterns of internationalisation"; and Christian Le Bas and Christophe Sierra, "Location versus home country advantages in R&D activities: some further results on multinationals' locational strategies," *Research Policy*, 31 (2002): 589–609.

Figure 2

Worldwide patent applications of German companies by regions and countries, 2012 to 2014
Percentage shares of weighted patent applications

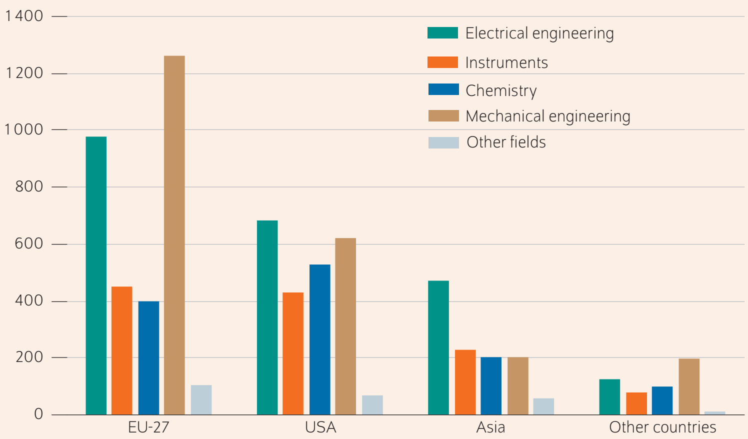


Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

The major research host regions for German companies are other EU member states and the USA.

Figure 3

Patent applications of German companies abroad by technology areas, 2012 to 2014
Weighted patent applications in absolute numbers



Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

Mechanical and electrical engineering are the dominant technological categories for R&D activities of German companies in other EU member states.

Depending on the level of the two measures of specialization, we were able to describe four internationalization strategies for a technological field in a foreign target region (see Table 3).

In the home-base augmenting, the company is strong in the relevant technological field at home and also has advantages in the host country. The company is using its complementary strengths abroad to build and add to the technological strengths it has developed at home.

In the home-base exploiting strategy, research is relatively weak in the host country and the company is applying the technological advantages it acquired at home there. This means that abroad, the company is seeking technical support for its sales and foreign production.

By following a technology-seeking strategy, the company is trying to compensate for its technological weakness at home by carrying out research in countries that are strong in those fields. In this way, research at top locations can open up access to new high technologies for them.

In the market-seeking strategy, technological motives do not play an important role because neither the company's home country nor the host country are specialized in the relevant field of research. Research abroad could be the result of a corporate takeover motivated by reasons that have little to do with technology.

Home-base augmenting internationalization strategy predominates

The home-base augmenting strategy predominates in internationalization: just under 50 percent of invention activity abroad falls into this classification (see Table 4). A further one-quarter of the activity can be attributed to the home-base exploiting strategy. Thus, three-quarters of the R&D activities of German companies abroad take place in research fields, in which by international comparison the companies have technological specialization advantages in their home country.[9] In most cases, research abroad is based on the technological strengths of research in Germany.

Only 12 percent of patents abroad indicate a technology-seeking strategy in which the company carries out research abroad in fields in which it is not specialized in a host country that does have technological advantages. We can assume that companies pursue this strategy in order to acquire new technological knowledge at top foreign research locations. With above-average frequency, companies from Germany follow the technology-seeking strategy in the computer technology, optics, data processing, and digital communication

9 In comparison with an older study of 87 German companies, the proportion of the two strategies has remained approximately the same since the mid-1990s. However, the proportion of the knowledge-building strategy has become somewhat higher than that of the knowledge-using strategy. See Patricia Laurens et al., "Internationalisation of European MNCs R&D," *Management international*, 19(4) (2015): 18–33.

technological fields. This strategy is rarely used in the technological fields of mechanical engineering and chemicals.

While electrical engineering companies follow all four internationalization strategies to a similar extent, the clear focus in mechanical engineering, chemicals, and instrument technology is the home-base augmenting strategy in which the company is specialized in the relevant technologies both at home and in the host countries. Companies that follow this strategy are combining the technological advantages of the company at home with the relevant technological advantages abroad.

An above-average share of German companies follow technology-seeking strategies in the U.S., Austria, Denmark, and South Korea – all extremely research-intensive countries. German companies tend to carry out the home-base augmenting strategy in neighboring European countries. Most research in China is clearly following the home-base exploiting strategy, which primarily aids in adapting products and processes to the conditions in the target country.

And the six German companies with the largest number of patent applications primarily follow the home-base augmenting strategy. Obvious differences are apparent in the significance of the technology-seeking strategy. At BASF, Siemens, and Infineon, it has a share of approximately 20 percent – significantly higher than the average of all companies. Bosch has an above-average proportion with regard to the home-base exploiting internationalization strategy, meaning that it researches abroad in many technologies to support its sales and local production.

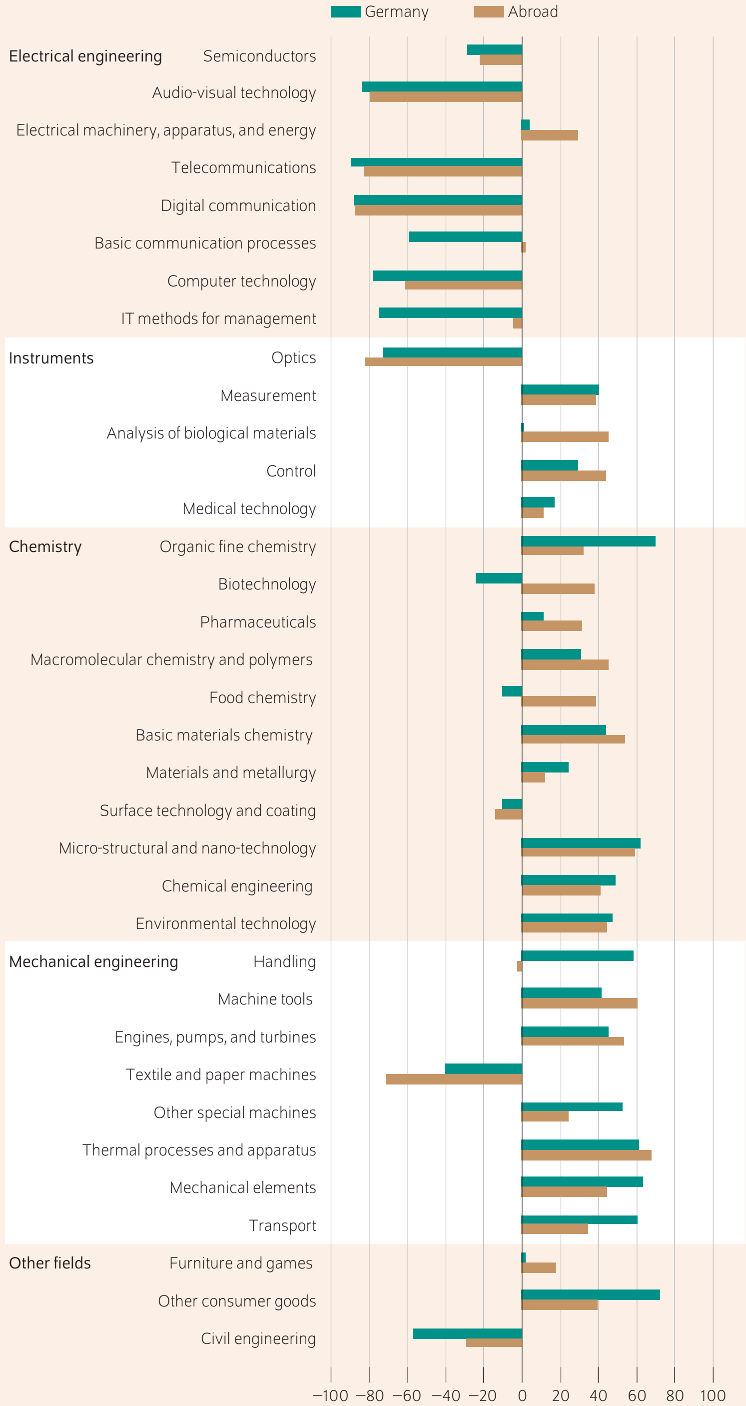
Conclusion: Research abroad supports technological strengths in Germany but also reveals deficits in digitalization technology

Although a solid 25 percent of the inventions of globally active German companies are developed abroad, most of their innovative power is still determined by their R&D performance in locations at home: companies from Germany typically carry out research abroad from a position of technological strength at home. In Germany's high-performance focal areas of research – mechanical engineering, chemicals, and measurement and control technology – company research activities abroad supplement and enhance the knowledge developed at home. Another key motive is using the domestic knowledge advantage to adapt process and products to conditions and customer requirements abroad.

As a research location, Germany does not sacrifice any technological strength as a result of its companies' international activities. Research that is carried out in addition to technological activities at home or to support market development is not an indication of "relocation." Actually, German companies use some internationalization strategies to compensate for their technological deficits at home. They are not very significant in relative terms, but companies follow them for technologies whose importance is increasing within the

Figure 4

Technological specialization (RTA) of German companies at home and abroad, 2012 to 2014



Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

Overall, German companies have specialized in the technological areas mechanical engineering and chemistry.

Kasten 2

Revealed technological advantage index (RTA)

In order to determine the technological fields in which individual companies or corporate groups have specialized by country or region, we used the revealed technological advantage index (RTA). It was originally used to measure international trade specialization but was soon applied to quantifying technological advantage based on patent data.[1] The RTA index measures the relative concentration of invention activity (patent families *p*) of a company on specific technologies in comparison to a population of companies. It is defined as follows:

$$RTA_{tr} = (p_{tr}/\sum_t p_{tr})/(\sum_t p_{tr}/\sum_{tr} p_{tr})$$

In the equation, *t* stands for the technological field's index and *r* for the index of the respective company. To classify the internationalization strategies, the technological advantage of an individual company at home (RTA home) and the technological advantage of all the companies in a target country (RTA target) were measured.

Since the RTA scale runs from 0 to infinity and is difficult to interpret intuitively, it was transformed as follows:

$$RTA\_mod_{tr} = 100 \times tanh\ ln(RTA_{tr})$$

By converting the RTA with the hyperbolic tangent of the original RTA's logarithm, the RTA becomes a symmetrical measure with values between -100 and +100.

A value of 0 means that the proportion of a technological field in the particular company equals the average proportion of the field in all companies. The index assumes a negative value (maximum -100) when the proportion of patent applications by the examined company in the technological field under observation is smaller than the proportion in all companies, indicating that the company has no advantage. Positive values (maximum +100) show an above-average proportion of patents in these fields and therefore, reveal a company's technological advantage in the relevant technological field.

1 Keld Laursen, "Revealed comparative advantage and the alternatives as measures of international specialization," *ILR Review* 5 (2015): 99–115.

context of digitalization: computer technology, IT methods for management, and digital communication technology. These research fields must also be strengthened in Germany in order to improve the way knowledge acquired abroad is integrated into the home location and pave the way for leveraging innovations at home.

Table 3

Internationalization strategies of companies R&D

Technological Specialization		...of host countries: strong	...of host countries: weak
...of companies at home	strong	(1) home-base augmenting HomeRTA > 0 HostRTA > 0	(2) home-base exploiting HomeRTA > 0 HostRTA < 0
	weak	(3) technology-seeking HomeRTA < 0 HostRTA > 0	(4) market-seeking HomeRTA < 0 HostRTA < 0

1 Revealed technological advantage (RTA), see box 2 in this report

Sources: Compiled by the authors on the basis of Christian Le Bas and Christophe Sierra (2002): Location versus home country advantages in R&D activities: some further results on multinationals' locational strategies. Research Policy, 31.

Table 4

Internationalization strategies of German companies by technological category, host country, and six top patenting German companies, 2012 to 2014

Percentage shares

	Internationalization strategies				
	Home-base augmenting	Home-base exploiting	Technology-seeking	Market-seeking	Total
Total	50	27	12	11	100
Technological area:					
Electrical engineering	31	26	18	25	100
Instruments	61	20	14	5	100
Chemistry	57	29	9	5	100
Mechanical engineering	60	28	6	6	100
Other fields	37	42	16	5	100
Host country:					
USA	47	26	16	11	100
Austria	54	15	14	17	100
France	61	24	4	11	100
China	12	79	5	5	100
United Kingdom	50	22	6	22	100
Sweden	63	27	2	8	100
Italy	67	11	8	14	100
Swiss	56	25	8	11	100
Denmark	50	21	20	9	100
Japan	41	47	9	3	100
South Korea	27	29	36	8	100
Other country	56	22	12	10	100
Company:					
Siemens	43	27	19	12	100
Bosch	45	39	8	9	100
Infineon	53	5	19	23	100
Volkswagen	59	21	6	14	100
Continental	55	16	11	18	100
BASF	42	28	20	11	100

Sources: Institute for Prospective Technological Studies und OECD Directorate for Science, Technology and Innovation (EC-JRC/OECD COR&DIP© database, v.1. 2017); Europäisches Patentamt (PATSTAT v5.11); authors' own calculations.

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