Tradable planning permits in the field: Executive experimental results from Germany

Ralph Henger[a,*], Tim Straub[b], Christof Weinhardt[c]

[a] German Economic Institute, Global and Regional Markets, Real Estate Economics, Konrad-Adenauer-Ufer 21, 50668 Koln, Germany
[b] FZI – Forschungszentrum Informatik, Haid-und-Neu-Str. 10–14, 76131 Karlsruhe, Germany
[c] Karlsruher Institut für Technologie (KIT), Kaiserstraße 89, 76133 Karlsruhe, Germany

ARTICLE INFO

Keywords:
Urban sprawl
Land development
Trading system
Field experiments

ABSTRACT

In countries such as Germany, where municipalities have planning sovereignty, problems of urban sprawl often arise. As the dynamics of land development have not substantially subsided over the last years, the national government decided to test the instrument of 'Tradable Planning Permits' (TPP) in a nationwide field experiment with 87 municipalities involved. The field experiment was able to implement the key features of a TPP system in a laboratory setting with approximated real socioeconomic and planning conditions. In a TPP system allocated planning permits must be used by municipalities for developing land. The permits can be traded between local jurisdictions, so that they have flexibility in deciding how to comply with the regulation. In order to evaluate the performance of such a system, specific field data about future building areas and their impact on community budgets for the period 2014–2028 were collected. The field experiment contains several sessions with representatives of the municipalities and with students. The participants were confronted with two (municipalities) and four (students) schemes. The results show that a trading system can curb down land development in an effective and also efficient manner. However, depending on the regulatory framework, the trading schemes show different price developments and distributional effects. The unexperienced representatives of the local authorities can easily handle with the permits in the administration and in the established market. A trading scheme sets very high incentives to save open space and to direct development activities to areas within existing planning boundaries. It is therefore a promising instrument for Germany and also other regions or countries with an established land-use planning system.

1. Introduction

The four-year average of land take for settlement and traffic areas in Germany was 52 ha per day from 2015 to 2019 and has constantly decreased over the last years (UBA, 2021). However, the conversion rate from open space to developed land is still much higher than the '30-hectare target' laid out by the Federal Government in 2002 originally formulated for the year 2020 and then postponed to 2030 (BMUB, 2016). The sustained loss of open space is also incompatible with the long-term goal to achieve 'Land degradation neutrality' in Germany and the EU by 2050 (EU Comission, 2011; Wunder and Bodle, 2019).

There are many reasons for the high rate of land development and the accompanied trends of urban sprawl in Germany (Henger and Thoma, 2009, 2018). One main reason is the general regulatory framework set for municipalities, landowners, and developers, which has not been reformed e.g., reform of the building code 2013) substantially changed over the last years (UBA, 2019; Gotze and Hartmann, 2021). At present, many actors involved in the land development process can still benefit when arable land is turned into new building areas. Key drivers are municipalities and local politicians which can signal with new building areas their capacity to act, to solve problems like housing shortage, while attracting new families with high incomes. This regulatory issue is especially a problem in countries like Germany where land-use planning is implemented on a local level. In fact, local planning is incorporated in comprehensive planning at regional and state level, which has also been strengthened over the last years. However, municipalities in Germany have planning sovereignty and are the key actor in the land development process as they are responsible for drawing up urban development plans (land use and building plans) (Wegener, 2016).

* Corresponding author.
E-mail addresses: henger@iwkoeln.de (R. Henger), straub@fzi.de (T. Straub), weinhardt@kit.edu (C. Weinhardt).

Numerous studies have proven that inefficient decisions in the land development process are leading to severe impairments of the environment and to high costs for the society. The costs include charges and taxes for providing and maintaining the necessary public infrastructures and services (e.g., street lighting, waste management), especially in low-density, suburban areas (Schiller and Siedentop, 2005; Siedentop et al., 2006). In the decade 2010–2019, however, pressures on land had fostered by economic and population growth (Henger and Voigtlander, 2019). Because of current housing shortages in many big cities and agglomeration areas in Germany, the public and also scientific debate has shifted from one about vacancies and sprawling settlements to one about how to realize more housing with achieving the land-saving targets that have been set. One of the key challenges for land-use policies is therefore on how housing construction can be substantially decoupled from land development.

There is a wide range of policy options for preserving natural resources and biodiversity also in Germany (Millward, 2006; Nuissl and Schroeter-Schlaack, 2009). Those containment strategies have brought improvements but were until now unable to curb down land development sufficiently. Additionally, many instruments like local quantity targets have the potential to operate effectively but are accompanied with negative (welfare) effects on regional markets.

German economists and legislators have therefore highlighted the advantages of market-based instruments, like 'Tradable Planning Permits' (TPP) (Kock et al., 2008; Henger and Bizer, 2010; Bovet et al., 2012; UBA, 2019). In a TPP system a municipality must submit planning permits to develop land outside existing planning boundaries. Municipalities are allowed to trade permits with other municipalities. This instrument can stimulate efficient land use, reduce existing incentives for local authorities to develop land on open space and guide demand in the direction of areas within existing planning boundaries (Nuissl and Schroeter-Schlaack, 2009; Bizer et al., 2011). Germany had started a nationwide pilot project commissioned by the German Environment Agency (Umweltbundesamt) to test a TPP-System nationwide. It ran from 2013 to 2019 and was carried out by a consortium of eight institution lead by the German Economic Institute (Institut der Deutschen Wirtschaft).

The pilot project consists of municipal case studies and experiments (UBA, 2019). The experiments had a two-dimensional research design with laboratory experiments and a field experiment that made it possible to answer methodologically design issues and to be able to assess the robustness of the results. The laboratory experiments are published in Meub et al. (2016a), (2016b), (2017) and Proeger et al. (2017a, 2017b, 2018) and are focussed on testing specific institutional parameters. The field experiment aims to test a TPP system in practice under most realistic conditions in a laboratory setting. This paper presents the methodology and the key results of the first nationwide field experiment and 87 municipalities involved. It contributes to the understanding of how a TPP system could work in practice and identifies key policy recommendations for a Germany-wide implementation. It is organized as follows: In the next section, we discuss the idea and the functioning of a TPP system and literature on related experiments. Section 3 presents the research design. Section 4 reports on the results, followed by a discussion in Section 5. Concluding remarks are presented in the last section.

2. Background and objectives

A TPP system is a German variation of a transferable development right (TDR) program which are operational in many countries like Canada or the United States (Nelson et al., 2012). It has specific characteristics as (i) it is not established on a small scale (within a particular municipality or region), (ii) it is not controlling landowners but municipalities, (iii) as it is not using specific zones, in where landowners can either only sell their rights ('sending areas') or buy their rights ('receiving areas') (Henger and Bizer, 2010). The basic idea of a TPP system is the limitation of new settlement and traffic areas, while preserving the maximum possible flexibility for regulated actors at the municipal level. By limiting land development with a cap-and-trade system open space gets a higher price, which ideally covers the entire environmental costs and spatial externalities associated with developing land. If open space does not receive an additional price that reflects the externalities of the land take, supply-creating building land strategies will remain attractive to municipalities in the future. As many studies for Germany have laid down, there is a lack of incentives for saving open space and for (re)directing developments into existing planning boundaries (Dillmann and Beckmann, 2018; Marquard et al., 2021; Nuissl and Siedentop, 2021). Additionally, municipalities have an incentive to offer building land attractive for residents and businesses, as those are in a competitive situation among themselves, which has similarities to a prisoner's dilemma (Kock et al., 2008; UBA, 2009a, 2009b; Wegener, 2016).

The fundamental theory of a TPP system was laid down in Bizer (1996) and Henger and Bizer (2010). Ostertag et al. (2010) and Henger (2013) provided first important indications of the functionality of a trading system. In addition, it was shown that the instrument can basically be considered efficient, effective, and also practicable. Various design options were developed in Bovet et al. (2012). The recommendations given in this study on the design were used for the field experiment presented here.

In a TPP system a municipality that wants to designate greenfield land outside existing planning boundaries for settlement or traffic purposes as part of a development plan must have and redeem one permit (i.e., certificate or allowance) for 1000 m^2 (0.1 ha) of land planned for development (Bovet et al., 2012; UBA, 2019). If it does not have enough permits, it can buy additional ones from other municipalities. To ensure the well-functioning organisation of trading, a land exchange market shall be set up nationwide. The total volume of permits for the municipalities is issued at the beginning of each year via a fixed key. The initial allocation key is based on the number of residents. Permits allocated at one time can be banked without any restrictions for future development (unlimited banking). Municipalities can pass on the costs of the permits to the final users of the land. The municipalities can also generate additional permits – so-called white permits – credited to them for withdrawing building rights by e.g., regreening planning and demolition measures. The rules in land-use planning and nature conservation legislation shall not be affected by the TPP system.

Within the pilot project five laboratory experiments were performed to examine design options for a TPP system and to check questions on the functionality of trading under controlled laboratory conditions in five different individual experiments (Meub et al., 2016a, 2016b, 2017; Proeger et al., 2017a, 2017b). One key result of the laboratory experiments is that a TPP system works more efficiently when initially the permits are allocated to the municipalities completely free of charge (grandfathering) (Meub et al., 2015). The reason for this is that a free initial allocation of the permits increases market efficiency while an auction system leads to inefficiencies. The laboratory experiments also show a high robustness of the system under different environments with specific conditions for the market participants (e.g. exogeneous economic shocks, Meub et al. (2016). The laboratory experiments are focussed in analysing the robustness of the market mechanism and are thereby limited in generalizing their results to 'non-laboratory' settings. The central objective of the field experiment is therefore the testing a TPP system under lifelike and most realistic conditions.

3. Study design

The field experiment presented here is a testbed experiment which aims to investigate the behaviour of municipalities in a realistic environment that also captures the essential characteristics of the proposed market design. The study design is based on a setting, which has been developed in Henger (2013) and also used in more laboratory framework by Meub et al. (2016a, 2016b, 2017) and Proeger et al. (2017a, 2017b).

The field experiment contains three components. At first, municipalities were selected in an acquisition process to participate in the pilot project. Then, data of every municipality was collected with a focus on their planning perspectives for a 15-year period (2014–2028) and a detailed evaluation of their planned building areas in this time. Finally, the experiments were performed by municipalities and by students with the prior collected data.

3.1. Research questions

To testing the TPP system in practice we involved all actors involved in the land development process in a municipality – from the planning offices and the treasurers to the mayor. In this realistic setting we could investigate how much of potential efficiency gains and gains from trade can be captured (see results in Section 4.1). We were also able to analyse whether a trading system can succeed in (i) reducing total land development for residential, commercial or traffic uses, (ii) directing development more toward areas within already existing planning boundaries or planned structures, and (iii) also directing development toward locations that are suitable in terms of their economic characteristics and also from a planning point of view. (Section 4.2). We are also interested in analysing the robustness and stability of the established market, in terms of price developments (Section 4.3), trading volume and speculation (Section 4.4). As a market basically also leads to financial effects, we also investigate what kind of municipalities gain or loss money in the permit market (Section 4.5). Another objective of the field experiment is developing and testing most likely options for the design of a TPP system to be able to derive recommendations for implementation.

3.2. Selection of municipalities

The selection of municipalities taking part in the study began in the beginning of 2013. It was tried to cover a wide range of municipalities, so that the results of the experiments could also be applied on a nationwide TPP system. In addition, for a better analysis of the effects of competition on a regional and municipal level, local clusters were formed. All in all, 87 municipalities agreed to contribute to the pilot project. Three cities with more than 100,000 inhabitants participated. Moreover, several cities and municipalities from growing to shrinking regions from 12 federal states took part. Additionally, three municipalities with a strong regional connection and five municipality associations participated. The 87 municipalities are a balanced depiction of the diversity of the municipal landscapes in Germany. The municipalities represent 1.9% of the total German population and are responsible for 1.2% of land take in the period 2010–2013. Fig. 1 shows the comparison of distribution of the most important characteristics, distinguished by municipality classes. For each criterion, the percentages of the municipalities in the model are compared with those on the federal level.

The 87 municipalities ('Gemeinden') were represented by 38 'trade representatives' in the field experiment. This procedure was necessary because in some states, smaller municipalities can collaborate in a joint organisation ('Gemeindeverband') to perform administrative functions like land-use planning. In those municipalities the planning process is organised jointly while each member municipality has only to give legal permissions by their municipal councils ('Gemeinderat'). In fact seven "trade representatives' represented several municipalities (five municipal associations and two development agencies) in the field experiment.

In most cases, the trade representatives were heads of planning departments of their municipality. One municipality was represented by its treasurer, one by its mayor. Three municipalities were represented by several persons, in two cases by persons from the planning department together with the mayor and in one case by persons from the planning department and the treasury.

3.3. Data acquisition of the municipality

For creating a realistic environment all participating municipalities had to be reviewed in detail before the sessions took place. Therefore, a comprehensive survey based on a specially designed online platform was conducted in 2014 and 2015 to analyse all essential framing conditions as well as all building areas planned by the municipalities. Furthermore, the survey allowed a deeper analysis of the observed abatement strategies which were applied by the trade representatives to reach their objectives. The review included the following components, which are explained in detail in UBA (2019):

- Acquisition of all building areas planned for the period 2014–2028 with more than 2000 m^2 within (no permits required) and outside (permits required) existing planning boundaries.
- Ascertaining a detailed fiscal impact analysis of all building areas composed of all incomes and expenditures for a municipality over 25 years summed up in present value.
- Acquisition of existing and potential development opportunities within existing planning boundaries composed of brownfields, spaces between buildings, redensification areas and non-built-up areas with existing building permission.
- Acquisition of potential replanning areas and renaturation areas for the generation of white permits.
- Calculating the number of permits necessary for activating a building area and the number of permits for generating white permits.

A total of 540 building areas were recorded, fiscally evaluated, and calculated with their needed permits. Great importance was attributed to ensure that the representatives of the municipalities provided information for the long planning horizon until 2028 that was as realistic as possible.[1]

In terms of area 83% of the recorded building areas require permits and 17% do not need permits. For all 87 municipalities, the area subject to permits is 1498 ha and the total number of permits is 15,492. A total of about 22,500 housing units and 34,600 jobs are planned with the areas recorded for a 15-year period (2014–2028). Almost two-thirds (62%) of the sites are residential areas. However, because these are significantly smaller on average (2.4 ha of gross land per site) than the commercial areas (5.2 ha per site), the residential areas account for only 37% of the land recorded. 800 ha of residential land are compared to 1185 ha of commercial land (equivalent to 55% of the total area of all development areas). About seven percent of projects are mixed-use developments, which take up about nine percent of the gross area, averaging 5.2 ha per site.

All building areas recorded on the survey platform were subjected to a comprehensive fiscal impact analysis in preparation for the field experiment, the results of which were subsequently made available to local authorities. For this purpose, all additional revenues of the municipality triggered by a planning project (e.g., from increased tax revenue) are compared with the additional municipal expenditures (e.g., for apportionment payments or follow-up costs for technical and social infrastructures). The result of the fiscal impact analysis is a 'fiscal value' that corresponds to the actuarial present value, i.e., the sum of all additional revenues and expenditures discounted to the time of the project start over a period of 25 years. The fiscal values that the municipalities can redeem by activating their building areas had an average

[1] The used survey platform provided for several plausibility checks to give the municipalities concrete (warning) indications about the scope of planning and the most important information about the individual construction areas. Directly after the survey, the municipalities were asked online, using the Limesurvey platform, how realistic they considered their self-selected developments. The municipalities mostly assessed the total volume of developments derived as 'realistic' or 'high'.

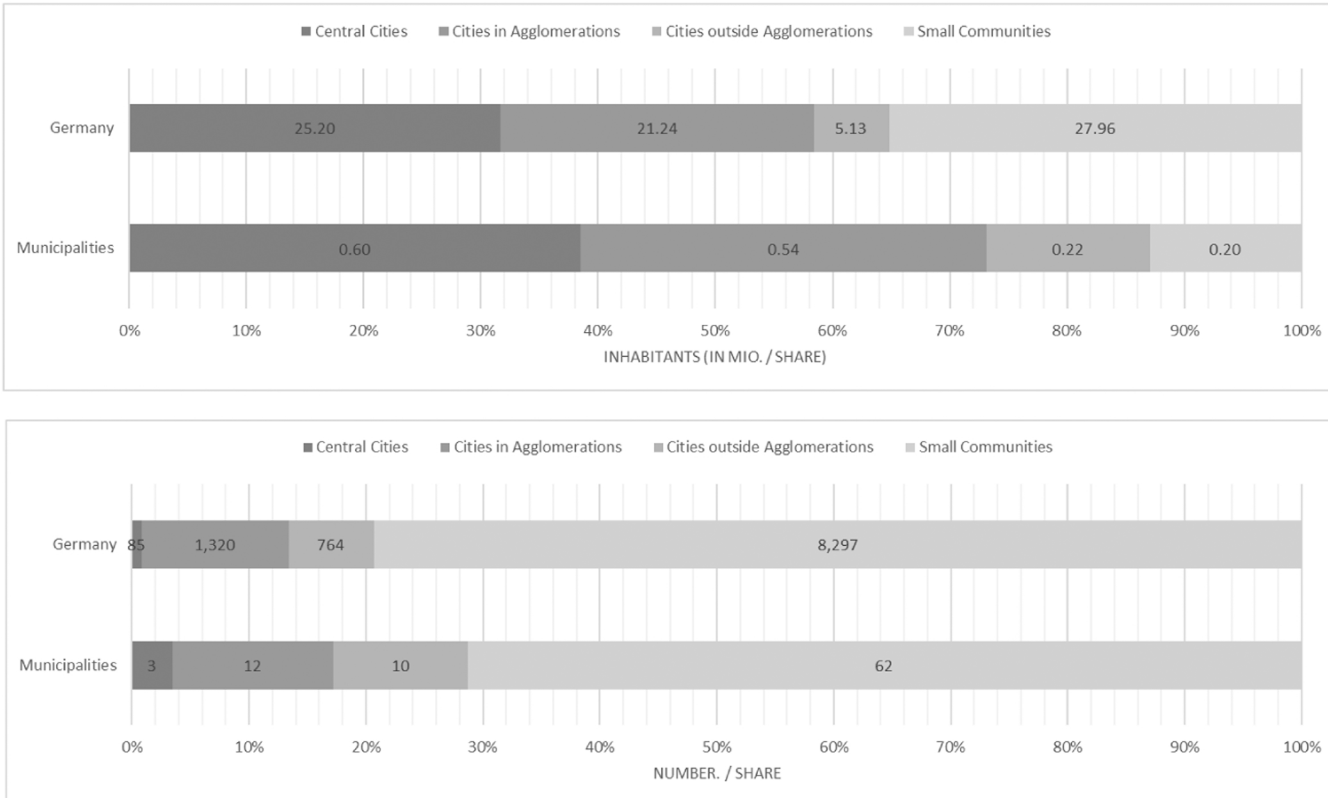


Fig. 1. Representativeness of the participating municipalities
Source: Statistisches Bundesamt; Notes: Data for land take partly without municipalities from Saxony-Anhalt and Saxony because of territorial reforms, municipality categories follow the typology of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (www.bbsr.bund.de).

of 85 euro per square meter.[2] Overall, the high percentage of building areas with negative fiscal values is noteworthy. Of all 540 building areas surveyed, 352 (65%) have a positive fiscal value, 187 (35%) have a negative fiscal value, and one development site has a fiscal value of zero.

A total of 47 white-permit areas were reported by 15 out of 87 municipalities. The areas are on average 6.0 ha in size, so that there is a potential for rezoning and deconstruction of 281.4 ha for the period 2014–2028 in total. Through this, the municipalities could theoretically generate 2444 white permits. The fiscal value for all areas is equal to an average of 6637 euros, or 6.64 euros per square meter.

3.4. *Experimental setting*

The sessions were conducted under controlled laboratory conditions at the Karlsruhe Design & Decision Lab (KD^{2}Lab) with a simulation platform specially developed for this pilot project. To test the two most likely implementation variants of a TPP system, a 'trading day' was organised on which all municipalities could simultaneously participate in a virtual TPP system based on their individually set framework with their specific data recorded for the period from 2014 to 2028 (see 3.2). On the trading day, two sessions were run with the 38 trade representatives of the 87 municipalities (field experiments). Each experiment was repeated with students under an identical framework (control experiments)). This procedure makes it possible to establish a most realistic framework (external validity) and to answer individual aspects and design options under controlled conditions (internal validity).[3] All students came from the Karlsruhe Institute of Technology (more than a half studying economics) and were selected via ORSEE (Online Recruitment System for Economic Experiments, Greiner, 2015) and hroot (Hamburg Registration and Organization Online Tool, Bock et al., 2014). The students were each assigned to a municipality randomly. The students were informed that they are representing a municipality acting in TPP system, but municipality names were anonymised. In contrast to the representatives of the municipalities, the students were paid as incentive for participating and acting in a realistic manner in the experiment.[4]

Fig. 2 shows the experimental setup. The first two settings differ in terms of the initial allocation of permits. In setting 1 all permits are issued annually to the municipalities free of charge (so-called grandfathering). In setting 2, the initial allocation is partially replaced by auctions. For this purpose, unilateral covered unit-price auctions were held annually before the current trading period, in which the federal government auctioned permits to the municipalities (see Fig. 3). This phased approach is also taken in the European Emissions Trading Scheme and allows the federal government (i.e., the states) to generate

[2] In total, all urban development projects with a positive fiscal value in the period from 2014 to 2028 would result in revenues of 1363 million euro. This corresponds to 90.85 million euro per year. In relation to the annual gross expenditure of the public budgets of all 87 municipalities amounting to 4068 million euro (as of 2013/2014), this corresponds to 2.2%.

[3] Laboratory experiments usually work with students as subjects to analyse market designs and the robustness of the results empirically. The control experiments with students give us the opportunity to validate and compare the outcomes with the results of the two sessions within the field experiment. Experimental methods in field experiments and laboratory experiments are well discussed e.g., in List (2011).

[4] In four control experiments a total of 152 students (4 sessions x 38 'combined' municipalities) participated. Payments were staggered in a tournament mode and were based on the income and expenditure from trade and the 'fiscal values' of the activated building areas. The participant earning the highest amount of virtual money received a payment of 26 euro. The lowest payment to a student was 15 euro.

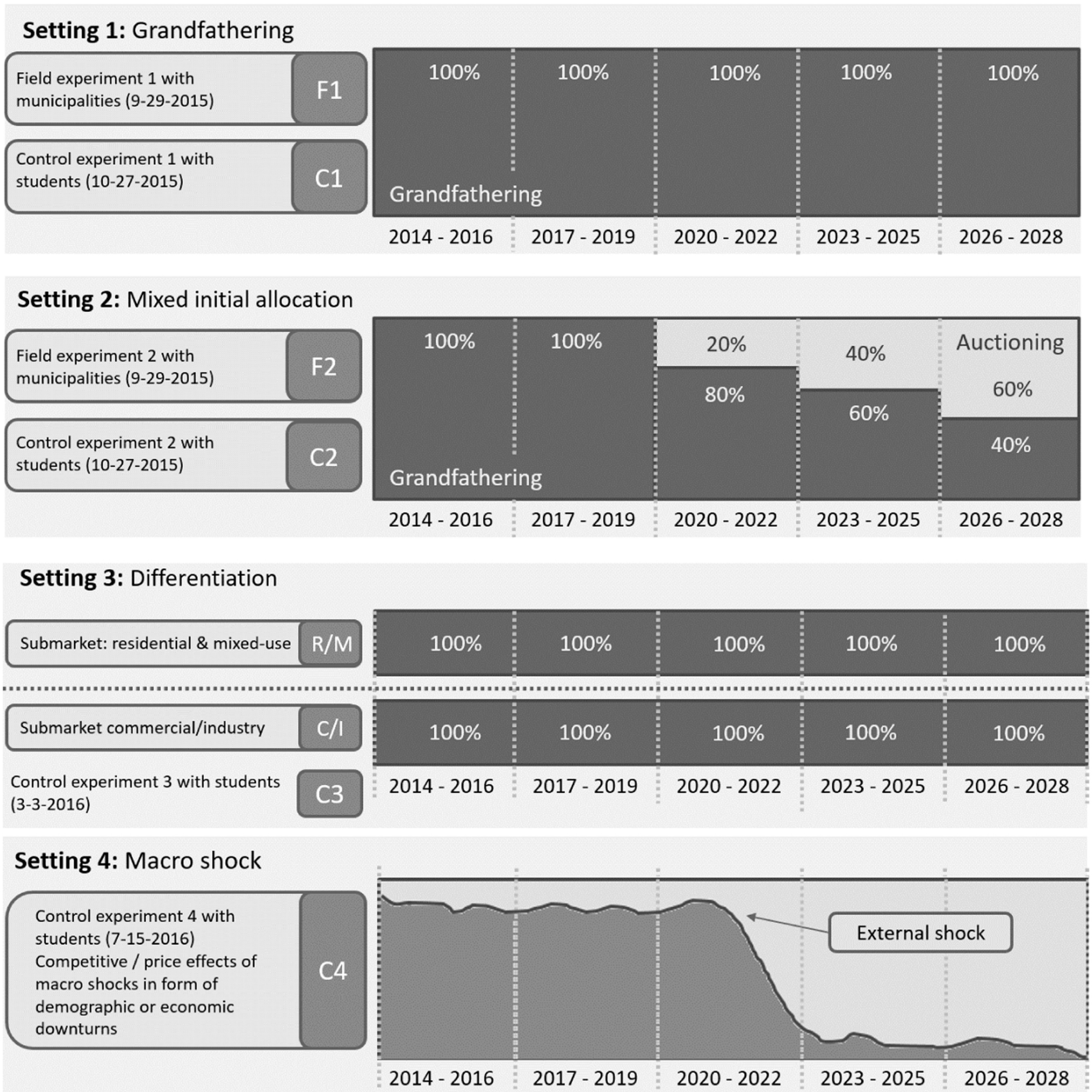


Fig. 2. Experimental setting
Source: Own figure; *The dates in parentheses indicate the day the experiments were conducted.

revenue that can then be used to finance funds to strengthen inner development, if necessary (Bizer et al., 2011; UBA, 2012). Auctions began in the year 2020. Initially, 20% of the total quota of permits was auctioned on a most-bid basis. In the following phases, the share was increased step by step by 20% points, so that in next phase (2023–2025) 40% and finally in the last phase (2026–2028) 60% of the total volume of issued permits was auctioned for a fee. Both settings were run once with the municipalities (F1, F2) and once with students in the control experiment (C1, C2).

Another two control experiments were conducted to analyse (i) a valuable option for a TTP system with two separated markets and (ii) the robustness and stability of the established market. In setting 3 the general market (as in setting 1) was separated in two markets, one for commercial and industry uses and one for residential areas and mixed uses. This makes it possible, to reach certain planning targets with the system according to types of use. Municipalities must therefore operate in two markets simultaneously.

Setting 4 includes an external shock into setting 1 to test the robustness of a TPP system. Participants were told that an economic crisis was imminent during the simulation period. One occurred in 2020, which was communicated to the participants via a message within the simulation platform. From this point on (2020), the fiscal value of the development areas was reduced by 25%. However, the course of the experiment was not changed by this shock, only that developments were less profitable from that point on.

All experiments were designed to achieve the Federal Government's

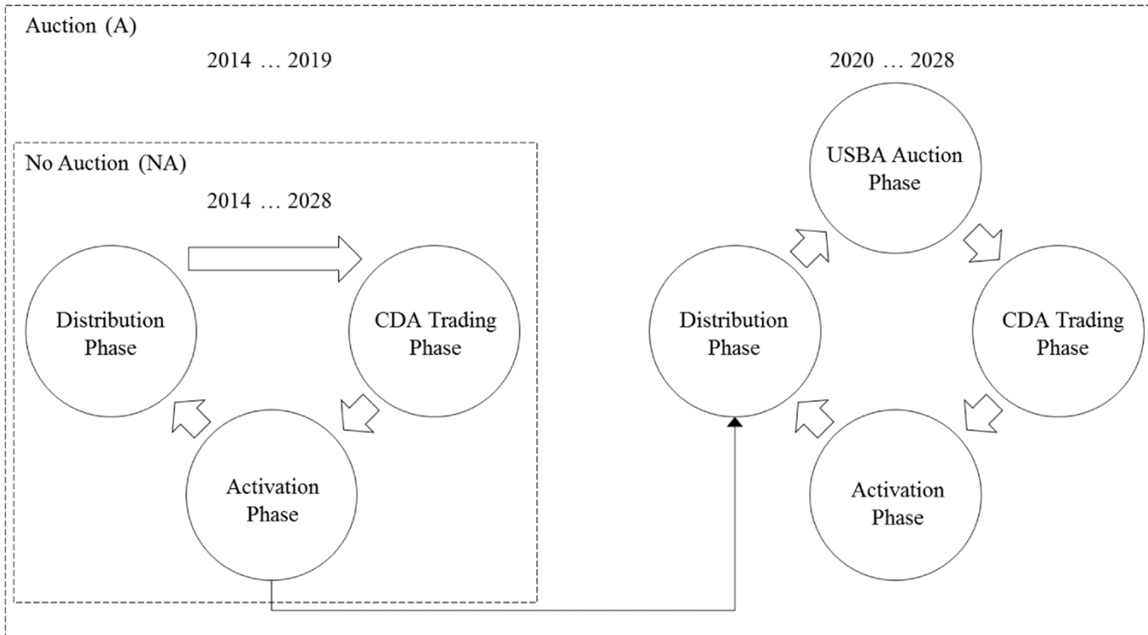


Fig. 3. Experimental phases
Source: Own figure; CDA = continuous double auction; USBA = uniform-price sealed-bid auction.

30-ha target in 2020 and thereafter further reducing land development to achieve 'Land degradation neutrality' in the long term. Thus, in the experiments, federal land take targets were gradually reduced from 55 ha per day (2014–2016) to 42.5 ha per day (2017–2019), to 30 ha per day (2020–2022), to 25 ha per day (2023–2025), to 20 ha per day (2026–2028). Within the quantity framework of the settings, land developments not initiated by local governments (e.g., highways) were included with a flat rate of 20% of the total federal land-saving targets (see Henger et al., 2019, pp. 135).

In each experiment, 15 years were simulated in which the participants could 'activate' their recorded building areas (see 3.2). To activate these building areas the participants had to use permits. The number of permits required depended on the location (interior and exterior) and the size of the development area. Permits were allocated annually free of charge depending on the size of the represented municipality and could be traded on the market platform between participants in a continuous double auction (CDA).

In each experiment, all participants went through 15 years (2014–2028) and, within each year, several phases (Fig. 3). Session 1, 3 and 4 consisted of 3 phases. The first phase is the free initial allocation. Here, the participants receive permits free of charge depending on the size (number of inhabitants) of the municipality. In the second phase, the trading phase, participants could buy and sell permits at any time within three minutes (CDA). All price-quantity bids are anonymously ordered by price in an order book (with a maximum depth of five bids per buy and sell side) and were visible to all participants. In the experiment, bids could be accepted at any time by all other participants up to the maximum quantity offered. All bids were carried over to the next year. In addition to the bids placed in the order book, the current market price was also public information for all. During the trading phase, all construction areas could be viewed. The fiscal value displayed here served as an orientation value for the participants as to how much they should spend at most for a permit to continue to make a profit through the implementation of the development area. In the third phase, the so-called activation phase, the development areas could be activated or developed. If the permits needed for the development areas exceeded the current stock, the development areas could not be realised. Unused permits did not expire. They were transferred to the rights account of the next period and could be used without restriction ('unlimited banking'). By implementing building areas, the fiscal value of the corresponding building area was credited to the participant's account as a credit. The participant could use these again in the next trading period to buy further permits.

Session 2 (F2, C2, see Fig. 2) extends the basic scenario by an auction. A uniform-price sealed-bid auction (USBA) was used as auction procedure. In this form of auction, all bidders pay a uniform price for each right acquired. The bidders submit hidden price-quantity bids. All bids are ranked by price and served from top to bottom. The highest bids receive the total number of their desired bids at a uniform price. The last bid served receives the quantity still available and sets the unit price. The unit price auctions were held every year from 2020 onwards in the so-called auction phase directly after the free allocation and before the trading phase. The auction phase consisted of two sub-stages. In the first stage, all participants could submit price-quantity bids within 1.5 min each. They were informed about the number of permits to be auctioned and the current holdings of their permits. In the second stage, participants were informed whether and how many permits they received at the auction and at what price. The results of the auction were automatically transferred to the corresponding accounts.

All settings set an annual limit for the fiscal budgets. This restriction was implemented to achieve a higher external validity as municipalities cannot overspend their budgets indefinitely. The simulation platform contained a 'budget balance sheet', in which the participants were always informed about the status of their budget. The status was instantly updated with the income and expenditure from trade and the fiscal values of activated building areas and white-permit areas. The annual limit corresponded to 25 per cent of the municipality's annual budget. If a participant exceeded this limit through an action, they received a notice, and the action was not feasible. Participants who exceeded 10 per cent of the budget received a notice that they were acting disproportionately and should reconsider their actions. In this case, the action could only be carried out by reconfirming. At the beginning of the experiments, the participants started with a credit balance of 0 euro.

4. Results

The presented statistical analysis of the results of the experiments are concentrating on differences between the observed outcomes and calculated theoretical predictions across the sessions. As the experiments did not yield sufficient independent observations for either parametric or nonparametric tests, the results are presented with summary statistical criteria, i.e., efficiency, gains from trade, price development, permit usage, trading volume, speculation, and distributional effects.

4.1. *Efficiency and gains from trade*

The market efficiency is calculated based on the fiscal values (see 3.2) and describes how much of these values can be achieved in relation to the optimum. In the experiments the fiscal values determine the redemption values for activating (i.e., developing) a building area and are therefore crucial for the trading decisions made by the subjects. The optimum is reached when the market leads to an outcome where the municipalities refrain from developing the building areas with the lowest fiscal values. Technically, market efficiency (or efficiency for short) is calculated by dividing the sum of the redemption values realized (in an experiment) by the sum of the redemption values in the competitive equilibrium. At 100%, the (welfare) optimum would be reached. The market efficiency achieved ranged from 67% to 92% in the six experiments. Considering the areas which can potentially be activated with banked permit at the end of the simulation in 2028 then the efficiency is higher within a range between 86% and 92% (Table 1).

The high efficiency outcomes confirm the results from previous experiments on a TPP scheme (Ostertag et al., 2010; Bizer et al., 2011; Henger, 2013). Compared to the results from similar market experiments in other regulatory fields – such as air pollutants – these are good results from an economic point of view, as the markets were able to organize the adjustment to the land-saving target much more cost-effectively compared to strict quantity targets without possible trading. This welfare improvement is usually expressed with the gains-from-trade. The gains of trade show how much market players can improve by their activity in the market compared to the initial allocation without trading. Gains from trade are calculated using a break term as follows: In the numerator of the term, the sum of the redemption gains potentially realized in an experiment is subtracted from the sum of the fiscal values without trading. In the denominator, the sum of fiscal values without trading is subtracted from the sum of fiscal values in the optimum. Before trading or without trading, the index is zero, since in this situation no improvement in the allocation of permits can occur. At the optimum or competitive equilibrium, the index is equal to one as the maximum of a possible improvement through trading could then be achieved.

The (potential) gains of trade achieved ranged from 28% to 77% in the six experiments. The gains of trade were slightly higher in the control experiments, with values reaching 75%, compared to field experiments, with 37% and 39%, respectively. This is not surprising as the representatives from the municipalities are more connected to the building areas and therefore not only focused on the fiscal value, which becomes a performance-based payment on these (see discussion in Section 5). Nevertheless, trading gains by municipalities also lead to a significant improvement in the allocation of the permits.

4.2. *Abatement strategies and generating white permits*

The participants' abatement strategies in the sessions differ regarding the different types of building areas as well as the location and fiscal values of the building areas. The participants' abatement strategies were mainly concentrated (i) on commercial areas, (ii) on areas outside existing planning boundaries and (iii) on developments with a negative fiscal value. About half of the commercial sites (51% on average of the six experiments) were activated, which is significantly less than the residential sites – of which 70% were activated. These findings follow a rational strategy of the participants. Commercial areas with an average fiscal value (61 euro per square meter) are usually more profitable than residential areas (85 euro per square meter). Therefore, in a permits scheme in which not all development areas can be realised, it makes sense to first give up commercial areas and unprofitable areas. These findings go hand in hand with the abatement of 67% of originally planned unprofitable construction areas. In contrast, only an average of 27% of building areas with a positive fiscal value were foregone. The results thus confirm that a TPP system not only reduces land development, but also enables participants to efficiently implement economically sensible areas through trading and to give up unprofitable areas. Additionally, we found that 96% of the land planned within existing planning boundaries and only 52% of the developments outside were activated. Developments are directed inwards, thereby minimizing urban sprawl.

Fig. 4 compares the development areas activated in the experiments with the original plans of the municipalities. The wide bars indicate the planned areas. The thin bars show the areas activated in the six experiments. Large adjustments took place, especially in the first years. In later years, developments that had initially been postponed were made up, with the result that in some periods development exceeded the targeted land-saving goals. This behavior is also visible in the banking rates, which express how high the share of permits not used for building areas is in a phase. As Fig. 4 and Table 2 show, over three-quarters (76–86%) of the permits in the market are not used from Phase I (2014–2016) to Phase II (2017–2019). In the next phases, the percentage of permits banked decreases. At the end of the simulation period, 7–24% of the permits remained unactivated (see potential efficiency and gains from trade in 4.1). Thus, a rather wait-and-see behavior of the participants could be observed especially at the beginning of the established market. This strategy makes sense from the point of view of the individual participants, as they can bank permits without costs. However, the sum of the decisions led to prices above the theoretical prices in competitive equilibrium, as this behavoir deprived available permits in the market and reduced supply.

The activation of the white permit areas had a high attractiveness for many participants in the field and control experiments. It was almost always possible to generate permits when the price level was high enough to get revenues, because the associated costs for the rezoning and deconstruction measures where lower then the value of the generated permits. Only 2 out of the 47 white permit areas had a fiscal value above 91 euros per square meter (see next sections), so that their deconstruction only proved economically advantageous in a few years

Table 1
Market efficiency and gains of trade.

	F1	F2	C1	C2	C3		C3	C4[a]	Optimum
					CI	**RM**			
Efficiency	90	92	67	91	88	89	89	90	100
Efficiency (potential)	90	92	89	91	88	90	90	90	100
Gains of trade	34	35	-110	64	53	74	69	37	100
Gains of trade (potential)	34	35	28	64	54	77	72	37	100

Source: Own table; Values in percent; Potential refers to the ability of participants to activate building areas with their banked permits at the end of the simulation in 2028.

[a] calculated without macro shock and 25% loss in value; CI: Market for commercial/Industry areas; RM: Market for residential and mixed-used areas.

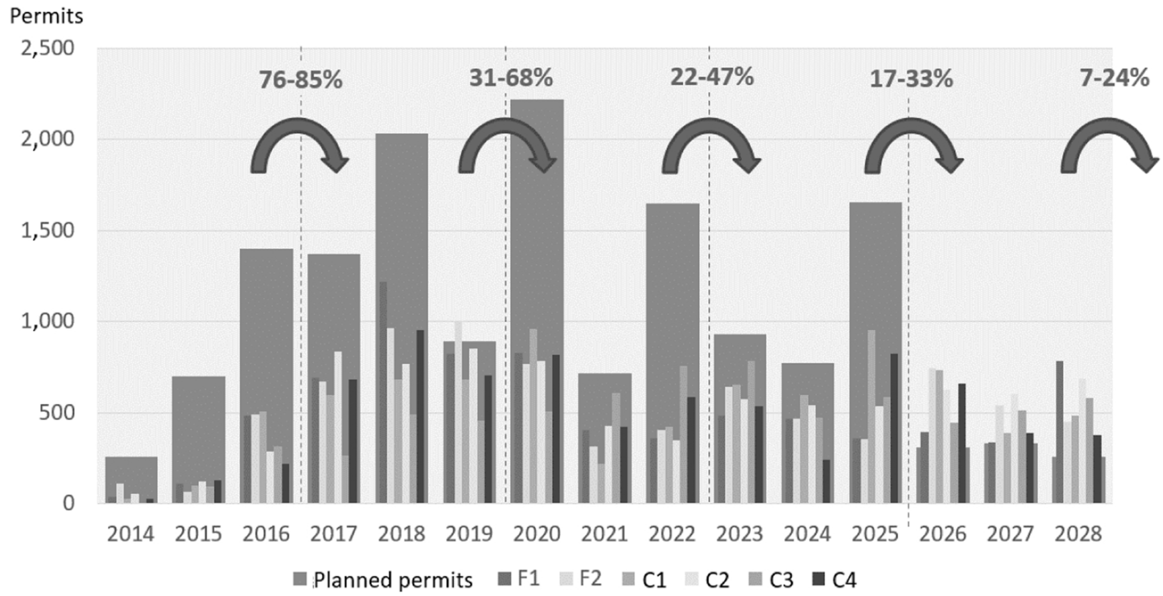


Fig. 4. Permits usage and banking
Source: Own figure; F1, F2 etc. = experimental settings.

Table 2
Permit usage und Banking.

	F1	F2	C1	C2	C3		C4
					CI	RM	
Permits							
Grandfathered permits	8425	7067	8470	7096	4975	3490	8470
Auctioned permits	–	1359	–	1371	–	–	–
White permits (activated)	211	201	215	218	428	145	214
Sum of permits in the market	8636	8627	8685	8685	5403	3635	8684
Used permits	7773	7982	7995	8040	4052	2814	7542
Not used permits	863	645	690	645	1351	821	1142
Banking as a percentage of percent transferred to the subsequent phase							
Banking Rate (2014–2016)	77	76	77	83	83	88	86
Banking Rate (2017–2019)	31	32	47	40	66	69	44
Banking Rate (2020–2022)	22	25	34	30	43	53	29
Banking Rate (2023–2025)	18	18	17	20	35	30	20
Banking Rate (2026–2028)	10	7	8	7	25	23	13

Source: Own table; CI: Market for commercial/Industry areas; RM: Market for residential and mixed-used areas; Due to rounding, there are slightly different results for the totals of allocated and auctioned permits.

during the simulations. All other areas, on the other hand, could always be deconstructed at a potential profit.

As Table 3 shows, only 13% of the white permit areas were not activated on average. This resulted in costs of 8.5 million euros in the field experiment. In the control experiments with students, the costs ranged from 5.0 (K2) to 12.3 (K3) million euros. When these costs are compared to the potential revenues, they could generate by selling the white permits for an average market price, a significant profit remains for the participants in all experiments. The market value of the white permits reached 23.7 million euros, so that participants could make a profit of 15.2 million euros on average.

Table 3
Using of white permits.

	F1	F2	C1	C2	C3		C3	C4
					CI	**RM**		
Costs for generating white permits) (Mio. €)	-8.5	-8.5	-9.4	-5.0	-5.6	-6.7	-12.3	-7.7
Market value of white permits (Mio. €)[a]	27.6	18.0	13.6	13.7	19.1	15.1	42.6	26.8
Market value minus Costs (Mio. €)	19.1	9.5	4.2	8.7	13.5	8.3	30.3	19.1

Source: Own table
[a] Calculated by multiplying the number of white permit areas activated multiplied by the average permit price in an experiment. CI: Commercial/ Industy areas; RM: residential and mixed-used areas

4.3. Price development

The average price of the six experiments reached the level of 91.02 euros per square meter of gross building land. This corresponds to a permit price of 91,020 euros (1 permit 1000 m^2). The long-term price level for permits was clearly above the theoretically optimal price of 6.15 euros per square meter, which was calculated for the competitive equilibrium in which the participants only focus on the financial aspects of the building areas. These findings can be explained on the interaction of several factors. One major factor is that there is a willingness to pay by the trade representatives of the municipalities for developing land also for areas with a negative fiscal value (33% of these areas were developed see, see 4.2). Building areas are judged on a variety of criteria so that land use decisions are not only based on financial considerations. In consequence prices were higher than the theoretical competitive price. The prices in the two experiments of the field experiment were significantly higher with an average of 110.15 euros per square meter compared to the control experiment with 66.45 euros per square meter.

The long planning horizons of cities and municipalities are another reason for the higher prices compared to theory. The participants behaved proactively, so that they banked permits, which reduced the overall quantity of permits (see 4.2). This observation goes hand in hand with earlier market experiments (e.g., Henger, 2013). In general, a market always needs some time to reach the optimum price level. The process takes longer if markets are not transparent, i.e., none of the participants is aware of how much the other market participants are willing to pay for a permit. A further reason is that the building areas could only be activated before the year the municipalities had planned to develop 'in reality' (set in the survey platform to realistically depict that a development area can only be developed when there is a certain demand, see 3.2). The participants were only allowed to postpone or to abate a building area.

These conditions made it difficult for the asks and bids to have a signaling effect and for prices to quickly align with prices in the long-term competitive equilibrium. This led to market prices at the approximate level of average fiscal values, which averaged 85 euros per square meter (see 3.2). These aspects are also closely related to the market conditions that participants faced in each year. As shown in Fig. 4, there is an inverted U-shape in terms of demand for permits over the period under consideration. The demand goes hand in hand with the theoretical prices, so that an inverted U-shape of the prices was also observed in the simulations, albeit at higher levels than theoretically predicted. We therefore conclude that the observed prices also reflect shortages in the market. Fig. 5.

4.4. Trading volume and speculation

The trading volume describes the sum of all transactions in continuous trading. Here, a distinction can be made between the total trade volume and the net transactions (trade balance), since trading allows all participants to buy and resell rights. The difference between total and net transfer volumes indicates how much speculation has taken place.

As Table 4 shows, trading volumes and transactions were significantly larger in the control experiments with students than in the field experiment with municipal representatives. The students were significantly more active in the market and executed almost twice as many transactions in which approximately twice as many permits changed hands. In terms of trading volumes in euros, these differences are no longer that high, as the price level in the two field experiments was almost twice as high as in the control experiment.[5]

The control experiments with the students show a significantly larger share of speculative trades that the participants were able to make with buying and reselling permits. While the municipal representatives, with rates of speculation of 16% and 8%, respectively, hardly speculated, i.e., acted simultaneously as buyers and sellers in the market, speculative trading was much more common among the students, with 44% and 28%, respectively. This result confirms the findings of experiments conducted before, in which a high propensity to speculate was also observed among students (Henger, 2013). The low interest for the municipal representatives for speculation was also to be expected with respect to the budgetary law. Of course, it is quite positive when municipality sell permits first and then acquire them again later when there is a need for development, so that less capital is tied up. However, there are limits since a municipality is obliged to use public money efficiently by law and therefore is restricted in speculative transactions.

Table 4 also shows the results from the auctions implemented in sessions F2, C2 and C4. During the auctions, the sale of 1359 permits in the field experiment generated 106.5 million euros (F2). The amount for sales was a little bit lower in the control experiments. These revenues go to the auctioneer and could be returned to the municipalities, for example, to subsidize developments within existing planning boundaries (e.g., brownfield development).

[5] F2 is kind of an exception. Here, municipalities showed in the actions much focused on their needs, so that they had to do significantly less trading in the secondary market (CDA).

4.5. Distributional effects and indebtedness

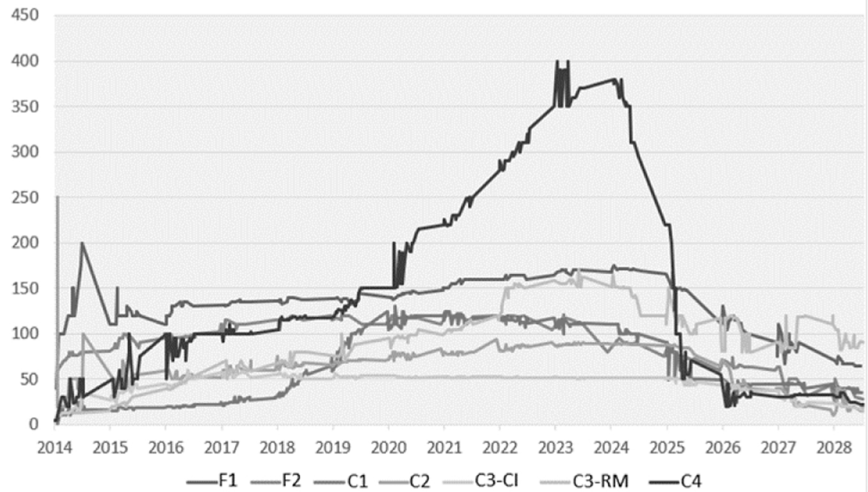
A TPP system leads also to capital flows across municipalities. Fig. 6 shows the trade balance of the four municipality classes described in Section 3.2. The total of the 'redemption values' for the participants amounts to around 1200 million euros and the trading volumes to around 300 million euros each. The differences between the six experiments in terms of trade balances reach a level of a few million euros, with the exception of K4 of up to a maximum of around 60 million euros. These differences appear small and therefore within a normal range of variation. We believe that the observations can be explained by the characteristics and strategies of the participants in the experiments. Core cities generate the highest revenue by buying and selling permits on the market. In Session 1, the three core cities generated revenues of 36.0 million euros in the field experiment with the municipalities (F1) and 41.8 million euros in the control experiment with the students (C1). In Session 2, however, the core cities only collected 4.7 million euros in the field experiment and even made losses of 16.3 million euros in C2. In all, the capital flows in the direction of the core cities.[6]

All three core cities in our pilot project are gaining population. The three other municipality classes, 'centers in metropolitan areas', 'centers in rural areas' and 'small municipalities' have a different population situation and are therefore differentiated into municipalities which are 'stable or growing' or 'shrinking', respectively. Shrinking municipalities are here those defined that lost more than 0.5% of their population between the end of 2011 and the end of 2013. This differentiation illustrates how a TPP system works. Growing municipalities tend to have to purchase additional permits and raise funds for this purpose. For shrinking municipalities, on the other hand, the opposite is true. This pattern can be seen in Fig. 6 in all three types of municipalities. A TPP system thus creates an equalization of burdens between municipalities developing more and those developing less. Municipalities can be rewarded for saving land and their chance of selling permits. They could use the revenues for strengthening developments within existing planning boundaries, e.g., revitalization of brownfields, or freely for other budget items, since earmarking of the revenues was not envisaged in the model test according to the non-affection principle (UBA, 2012).

In the two field experiments, the debt was 26.5 and 19.8 million euros, respectively (see Table 5). This corresponds to a total of only 2.2% and 1.6%, respectively, of the revenue potentially achievable by the municipalities in the field experiment. The maximum debt of a model municipality was 3.9% of the gross expenditure of the public municipal budget. Because of these low shares, we conclude that municipalities would be able to pay for all permits they are necessarily need for developing areas without overburdening.

In the control experiments, overall debt was higher than in the field experiments. Borrowing in the control experiments, with exception of K2, amounted to about 80 million euros and was about 3–4 times as high as in the field experiment with the municipalities. The maximum debt of a student was also significantly higher than that of the municipal representatives and reached 9.2% of the gross expenditures of the public municipal budget. The reasons for the higher indebtedness of the students compared to the municipal representatives is mainly because the municipal representatives acted more cautiously and did not try to make profits through speculative transactions. Overall, however, the students acted successfully in terms of market efficiency and trading profits achieved, too.

[6] However, it is difficult to assess whether this would also happen 'in reality', since for some years now many urban centers have been growing significantly because of strong external and internal migration, while many – mostly rural – regions have been struggling due to migration of parts of their population (Henger and Voigtländer, 2019).



Price per square meter	
F1	130.86 €
F2	89.45 €
C1	63.38 €
C2	62.83 €
C3-CI	44.63 €
C3-RM	104.03 €
C3	74.33 €
C4	125.25 €
Average	91.02 €

Fig. 5. Price development
Source: Own figure; F1, F2 etc. = experimental settings; CI: market for commercial/Industry areas; RM: market for residential and mixed-used areas.

Table 4
Trading volume and speculation.

	F1	F2	C1	C2	C3		C4
					CI	RM	
Number of transactions	335	402	751	703	526	303	521
Number of traded permits	2290	3429	4849	5939	3233	1766	4228
Trading volume (Mio. €)	299.7	200.2	307.3	281.9	144.3	183.7	529.6
Auction volume (Mio. €)	0	106.5	0	91.2	0	0	78.4
Trade balance (Mio. €)	252.6	185.0	202.7	204.0	94.4	132.3	295.7
Speculation (Mio. €)	47.1	15.1	104.6	77.9	49.8	51.4	233.9
Speculation in percent	15.7	7.6	34.0	27.6	34.6	28.0	44.2

Source: Own table; CI: Market for commercial/Industry areas; RM: Market for residential and mixed-used areas

5. Discussion of the results

The conducted field experiment was able to implement the key features of a TPP system in a laboratory setting with approximated real socioeconomic and planning conditions. Policymakers can therefore gain important insights for designing a trading scheme ex ante. The results also allow detailed conclusions about the effects for the municipalities and the development of building areas. We could observe high efficiency levels and gains from trade like in related studies before (e.g., Henger, 2013, Meub et al., 2016a) or in already implemented TDR systems (Nelson et al., 2012). We were also able to show, that growing municipalities must purchase additional permits while shrinking municipalities could sell them. This leads to a capital flow from dynamic to non-dynamic regions and creates an ecological burden-sharing mechanism. However, as municipal budgets are tight in many (also growing) municipalities and as current challenges of creating affordable housing are massive, policy-makers should be aware of concerns that many local politicians have about new financial instruments like a TPP system in practice.

However, we believe that the general results of the field experiment can be used for conclusions of the impact of a TPP system in Germany. The involved municipals represent the diversity of different types of cities and municipalities in Germany (see 3.2). The trade representatives from the municipalities are asked several questions, using the Limesurvey platform, directly after the experiments about their acting and their strategies in the trading scheme. 53% of the participants indicated that the decisions they made were 80% likely to be real decisions made by their municipality. Since only 9% of the participants reported values below or equal to 40%, we assume that most of the representatives were able to represent their municipalities in the simulations in a realistic way.

We see also lower net and gross trading volumes in the planner session, obviously because planners are also oriented on their planning objectives and their background information (e.g. Henger, 2013). The representatives oriented their actions also strongly to the needs of their municipality. For example, the participants stated that, they are mostly orientated to the market price, and secondly oriented towards their medium-term needs. The fiscal values and the political importance of the building areas as well as short-term and long-term-term bear a lower relevance. This illustrates that the municipal representatives have tried to include the multiple objectives of their municipality in their decisions. The fiscal values determined are just one guide for municipalities when making decisions on trading in land permits.

The prices in the experiments were on average higher than the theoretical optimal price. This can be explained due to the scarcity of the permits, the political objectives as well as the market power of some municipalities. It is important to emphasize that although prices were different in the experiments, the markets always performed efficiently. However, prices are important for the distributional effects of the system as well the acceptance of a system in practice.

We want also to stress that the results cannot be transferred 1:1 to reality, since some simplifications had to be made necessarily. One important limitation of our experiments is the field data set collected. Although it was collected and processed in close consultation with the municipalities, it is naturally based on general assumptions due to the long observation period of 15 years. The municipalities had to transform vague initial planning ideas into detailed planning with specific area-related and financial indicators. Strong assumptions also had to be made for some areas for the fiscal impact analyses. Even though the calculation of the fiscal effects was carried out using typical calculation

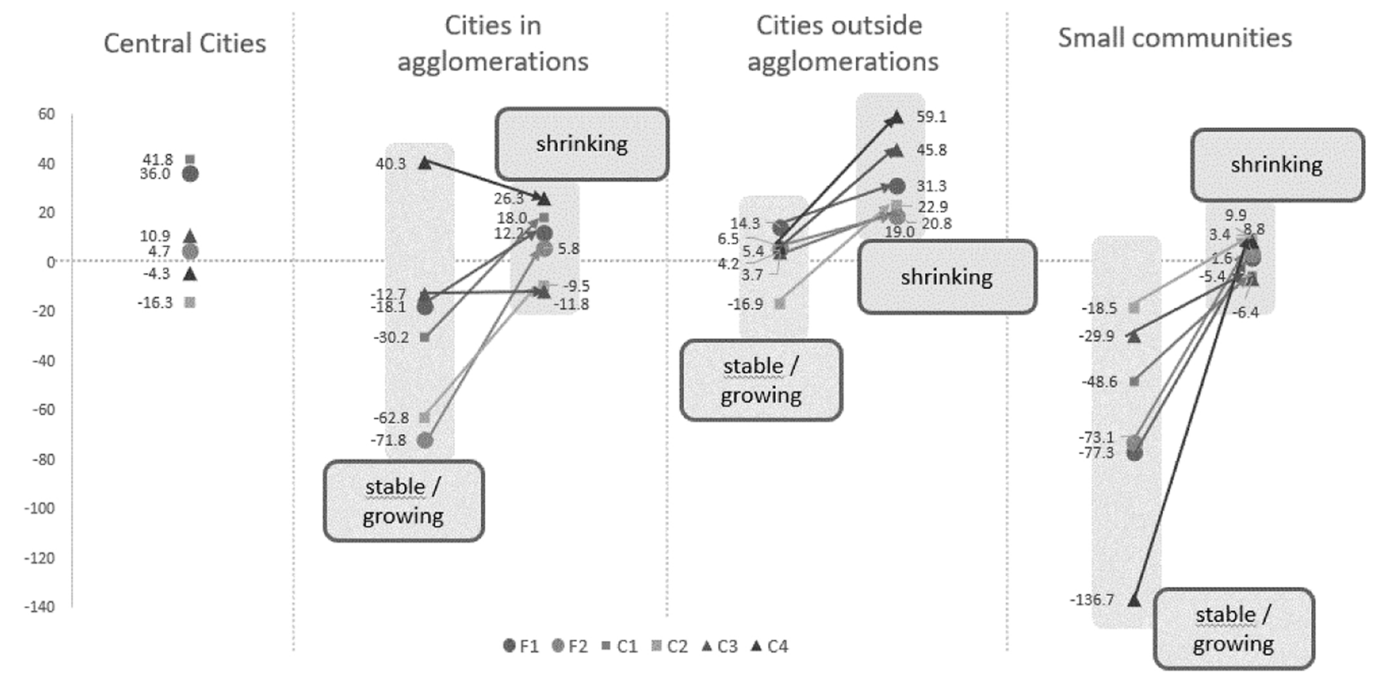


Fig. 6. Trade balance
Source: Own figure; Values in million euros; municipality categories follow the typology of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (www.bbsr.bund.de). F1, F2 etc. = experimental settings.

Table 5
Indebtedness.

	F1	F2	C1	C2	C3		C4
					CI	RM	
Indebtedness (Mio. €)	26.5	19.8	83.7	49.7	24.2	57.2	82.0
Redemption values (potential in Mio. €)	1195	1224	1204	1240	412	807	1224
Indebtedness in percent to Redemption values (potential)	2.2	1.6	7.0	4.0	5.9	7.1	8
Max. Indebtedness of a participant in percent of the fiscal household a municipality	0.7	3.9	7.5	6.2	9.2	8.0	6.7

Source: Own table; CI: Market for commercial/Industry areas; RM: Market for residential and mixed-used areas; Potential refers to the ability of participants to activate building areas with their banked permits at the end of the simulation in 2028.

values from the municipal planning offices.

Another important simplification is that representatives had to made decisions in a virtual research lab situation within seconds to represent their entire municipality within the trading system (corresponding to their planning scope). In reality, though, planning decisions are the result of a long-lasting negotiation process with many involved stakeholders. Based on the case studies (see UBA, 2019) and the surveyed data it has been possible to get insights into the decision structures and processes of the local administration. The results show that there are major interactions between local politics and the administration. However, there are many the interactions of actors and social institutional elements which could not be analysed detailly (Servillo and Van Den Broeck, 2012).

Another simplification was made as the building areas were exogenously given in the experiments. Obviously, this was made for the purpose of manageability, so that the building areas are immutable. Therefore, building areas were either considered as fully developed or fully non-developed within the experiment.

Finally, we want to point out the small sample size of our study and the small number observations. For this reason, the pilot project also conducted laboratory experiments to generate robust results with high internal validity (Meub et al., 2016a, 2016b, 2017; Proeger et al., 2017a, 2017b, 2018).

6. Conclusions

The presented field experiment shows how a TPP system can contribute to an effective reduction of land development in Germany. The trading scheme creates incentives to optimize land development decisions of the municipalities and organizes the abatement of land development outside existing planning boundaries very efficiently. In consequence, the measured market efficiency in the experiments was high, with values between 86% and 92%. The market participants were able to realize more areas through trading than with strict planning quantity caps. Overall, they were able to generate more revenues, so that there was an economic benefit initialized by trading. The high efficiency levels in the different settings of the experiments also show that a TPP system is robust with respect to framework conditions and uncertainties among market participants. We therefore consider a TPP system as a promising instrument not only for Germany but also for all countries with established land-use planning systems and ambitious land-use targets to reduce high rates of land development.

The field experiment could also demonstrate that the municipalities are able to participate well in a trading market after a short adaption phase, even if they had been unexperienced with market instruments beforehand. The TPP system also creates incentives for the forgoing of unprofitable development areas. As expected, the municipalities focus more on profitable projects with a positive impact on their local budget. Nevertheless, the municipalities still have the scope for implementing 'political' important projects, which are not inevitably profitable with respect to their fiscal outcome.

The results confirm the results found in Meub et al. (2015) that a TPP system is more efficient if the permits are initially allocated to the municipalities completely through grandfathering. The reason for this is that an additional auction mechanism leads to inefficiencies, uncertainties, and also strong redistribution effects. We can also show that the formation of two submarkets for commercial and residential uses leads to quite similar submarket efficiency levels and distribution patterns. Prices were significantly higher in the residential market than in the commercial market due to the higher average of fiscal values. We therefore conclude that a differentiation is a possible policy option to mitigate competition between commercial and residential land uses and to achieve certain development goals for the two individual uses.

The presented field experiment was able to implement the key features of a TPP system in a laboratory setting. However, future research should analyse the institutional framework of the complex municipal decision-making processes and investigate experimentally policy choices of local governments in a TPP system and in land-use policy generally.

Data availability

The authors do not have permission to share data.

References

Bizer, K., 1996. Handelbare Flachenausweisungsrechte zur Lenkung der gemeindlichen Ausweisung von Siedlungs- und Verkehrsflachen. In: Kohn, J., Welfens, M.J. (Eds.), Neue Ansatze in der Umweltokonomie. Metropolis, Marburg, pp. 367–383.

Bizer, K., Einig, K., Kock, W., Siedentop, S. (Eds.), 2011. Raumordnungsinstrumente zur Flachenverbrauchsreduktion: Handelbare Flachenausweisungsrechte in der raumlichen Planung. Nomos, Baden-Baden.

BMUB, 2016, Klimaschutzplan 2050: Klimaschutzpolitische Grundsatze und Ziele der Bundesregierung, Berlin.

Bock, O., Baetge, I., Nicklisch, A., 2014. hroot: Hamburg registration and organization online tool. Eur. Econ. Rev. 71, 117–120.

Colsaet, A., Laurans, Y., Levrel, H., 2018. What drives land take and urban land expansion? A systematic review. Land Use Policy 2018 (79), 339–349.

Dillmann, O., Beckmann, V., 2018. Do Administrative Incentives for the Containment of Cities Work? An Analysis of the Accelerated Procedure for Binding Land-Use Plans for Inner Urban Development in Germany. Sustainability 2018, 10.

EU Comission, 2011, The Roadmap to a Resource Efficient Europe, Brussels.

Gotze, V., Hartmann, T., 2021. Why municipalities grow: The influence of fiscal incentives on municipal land policies in Germany and the Netherlands. Land Use Policy 109, 729–737.

Greiner, B., 2015. Subject pool recruitment procedures: organizing experiments with ORSEE. J. Econ. Sci. Assoc. 1, 114–125.

Hartmann, T., Spit, T., 2015. Dilemmas of involvement in land management – Comparing an active (Dutch) and a passive (German) approach. Land Use Policy 42, 729–737.

Henger, R., 2013. Tradable planning permits to control land development in Germany: a laboratory testbed experiment. J. Environ. Policy Plan. 15 (2), 1–21.

Henger, R., Bizer, K., 2010. Tradable planning permits for land-use control in Germany. Land Use Policy 27 (3), 843–852.

Henger, R., Thoma, J., 2009. Fiskalische Wirkungsanalysen zur Bewertung der Siedlungsentwicklung – Ein (Fehl-)Versuch zur Flachenverbrauchsreduktion? Z. für Angew. Umweltforsch. 19 (1–2), 58–77.

Henger, R., Voigtlander, M., 2019, Ist der Wohnungsbau auf dem richtigen Weg? Aktuelle Ergebnisse des IW-Wohnungsbedarfsmodells, IW-Report 28/2019, Koln.

Kock, W., Bizer, K., Einig, K., Hansjürgens, B., Siedentop, S. (Eds.), 2008, Handelbare Flachenausweisungsrechte: Anforderungsprofil aus okonomischer, planerischer und juristischer Sicht, Baden-Baden.

List, J.A., 2011. Why economists should conduct field experiments and 14 tips for pulling one off. J. Econ. Perspect. 25 (3), 3–16.

Marquard, et al., 2021. Land consumption and land take: enhancing conceptual clarity for evaluating spatial governance in the EU context. Sustainability 2020 (12), 19.

Meub, L., Proeger, T., Bizer, K., Henger, R., 2016a. Experimental evidence on the resilience of a cap & trade system for land consumption in Germany. Land Use Policy 51, 95–108.

Meub, L., Proeger, T., Bizer, K., Henger, R., 2016b. The political economy of certificates for land use in Germany. J. Environ. Policy Plan. 19 (6), 712–732.

Meub, L., Proeger, T., Bizer, K., Henger, R., 2017. Die Effizienz von Zuteilungsmechanismen bei Flachenzertifikaten zwischen Versteigerung und Grandfathering - experimentelle Evidenz. Z. für Wirtsch. 66 (1), 80–109.

Millward, H., 2006. Urban containment strategies: a case-study appraisal of plans and policies in Japanese, British, and Canadian cities. Land Use Policy 23, 473–485.

Nelson, A.C., Pruetz, R., Woodruff, D., 2012. The TDR Handbook: Designing and Implementing Transfer of Development Rights. Island Press,, Washington.

Nuissl, H., Schroeter-Schlaack, C., 2009. On the economic approach to the containment of land consumption. Environ. Sci. Policy 12 (3), 270–280.

Nuissl, H., Siedentop, S., 2021. Urbanisation and Land Use Change. In: Weith, T., Barkmann, T., Gaasch, N., Rogga, S., Strauß, C., Zscheischler, J. (Eds.), Sustainable Land Management in a European Context, 8. Human-Environment Interactions, pp. 75–99.

Ostertag, K., Schleich, J., Ehrhart, K.M., Goebes, L., Mueller, J., Seifert, S., Kuepfer, C., 2010. Neue Instrumente für weniger Flachenverbrauch. Der Handel mit Flachenausweisungszertifikaten im Experiment. Fraunhofer Institut,, Karlsruhe.

Proeger, T., Meub, L., Bizer, K., 2017a, The role of communication on an experimental market for tradable development rights. cege discussion paper 271. Universitat Gottingen.

Proeger, T., Meub, L., Bizer, K., 2017b, Tradable development rights under uncertainty: an experimental approach. cege discussion paper 270. Universitat Gottingen.

Proeger, T., Meub, L., Bizer, K., 2018. Laboratory Experiments of Tradable Development Rights: A Synthesis of Different Treatments. Sustainability 10 (6), 1–19.

Schiller, G., Siedentop, S., 2005. Infrastrukturfolgekosten der Siedlungsentwicklung unter Schrumpfungsbedingungen. DISP: Dokumente und Informationen zur Schweizerischen Orts-. Reg. - und Landesplan. 1, 83–93.

Servillo, L.A., Van Den Broeck, P., 2012. The social construction of planning systems: a strategic-relational institutionalist approach. Plan. Pract. Res. 27 (1), 41–61.

Siedentop, S., 2009, Einflussfaktoren der Neuinanspruchnahme Von Flachen. Forschungen. Bonn: BMVBS. Berlin.

Siedentop, S., Koziol, M., Gutsche, J.-M., Schiller, G., Walther, J., 2006, Siedlungsentwicklung und Infrastrukturfolgekosten – Bilanzierung und Strategieentwicklung. BBR-Online-Publikation 3/2006, Bonn.

UBA, 2009b, Von der Außen- zur Innenentwicklung in Stadten und Gemeinden. Das Kostenparadoxon der Baulandentwicklung. UBA-Texte 31/2009, Dessau-Roßlau.

UBA, 2009a, Gestaltung eines Modells handelbarer Flachenausweisungskontingente unter Berücksichtigung okologischer, okonomischer, rechtlicher und sozialer Aspekte. UBA-Texte 31/2009, Dessau-Roßlau.

UBA, 2012, Projekt FORUM: Handel mit Flachenzertifikaten Fachliche Vorbereitung eines überregionalen Modellversuchs, UBA-Texte 60/2020, Dessau-Roßlau.

UBA, 2019, Modellversuch Flachenzertifikatehandel – Realitatsnahes Planspiel zur Erprobung eines überregionalen Handels-systems mit Flachenausweisungszertifikaten für eine begrenzte Anzahl ausgewählter Kommunen, UBA-Texte 116/2019, Dessau-Roßlau.

UBA, 2021, Flachensparen – Boden und Landschaften erhalten. ⟨https://www.umweltbundesamt.de/themen/boden-landwirtschaft/flaechensparen-boeden-landschaften-erhalten#flachenverbrauch-in-deutschland-und-strategien-zum-flachensparen⟩ (accessed 08 October 2021).

Wegener, M., 2016. Government or governance? The challenge of planning for sustainability in the Ruhr. In: Hartmann, T., Needham, B. (Eds.), Planning By Law and Property Rights Reconsidered. Routledge, pp. 157–170.

Wunder, S., Bodle, R., 2019. Achieving land degradation neutrality in Germany: Implementation process and design of a land use change based indicator. Environ. Sci. Policy 92, 46–55.