RETAX

Literature review – Impact of the property tax on energy efficiency and sustainable land use

Taranu Victoria & Verbeeck Griet

Voor meer informatie over deze publicatie victoria.taranu@uhasselt.be

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ABSTRACT

Theoretically, the property tax can be used as a policy to steer sustainable behaviour in the residential sector. Property tax reductions can incentivise investments in energy efficiency, or different tax regimes can be used as levers to encourage sustainable land use. However, is property taxation an effective tool to achieve environmental policy goals? This paper presents findings of a literature review of ex-post empirical studies regarding the efficacy of the property tax to encourage sustainable land use and energy efficiency in the residential sector. Findings show mixed results using property tax incentives to increase the deployment of solar thermal and PV systems in the residential sector. Results differ by country, and they might be explained by the difference in the design of the property tax incentive that affects its visibility, the effective size and the ease with which it can be claimed. Other studies point out that the property tax can be an effective tool for sustainable land use policies such as limiting the urban sprawl. However, the design of the property tax has to be carefully considered, as different tax regimes such as differential rates on land and structures can affect the construction activity in terms of location, size of housing units and density patterns.

INTRODUCTION

The property tax is used to raise revenue to provide public goods and services and can contribute to horizontal and vertical equity. At the same time, it can be used to steer behaviour in the residential sector, for example, to stimulate investments in energy efficiency and sustainable land use. In the EU, the building stock is responsible for 36% of the total CO_2 emissions; therefore, it has an essential role in decarbonising the energy system by 2050 (EC 2018). Buildings are no longer seen as passive consumers but as contributors to decentralised renewable energy (RE) generation and storage.

Besides the share of CO_2 emissions accounted to buildings, the residential building stock indirectly contributes to climate change due to its configuration. Urban sprawl[1], characterised by low-density developments scattered beyond urbanised areas (Song and Zenou 2006), implies longer commuting distances (Brandt 2014), reliance on private automobiles (Song and Zenou 2006) and excessive land use (Brandt 2014). The increase in commuting distances and reliance on automobiles contributes to CO_2 emissions and negative environmental impact. Furthermore, land-use changes can cause negative externalities such as air and water pollution, degraded biodiversity, and risk of flooding because of increased sealed surfaces (Polyakov and Zhang 2008).

This paper aims to investigate whether the property tax can be used to steer sustainable construction patterns and increase the energy efficiency of the residential sector in an efficient manner. Property taxation can affect the decisions of landowners on how and when to build (Wenner 2018). Not in the least because one can differentiate between the taxation of land and structure. This differentiation can be implemented in the estimation of the tax base, in the tax rate or the type of property tax regime (land value tax, split-rate tax or a tax on structures). Aside from density patterns of residential developments, different tax regimes can influence the size of dwellings or the size of the plots, contributing to sufficiency measures[2] such as reduction of m^2 living area per resident. Specific tax regimes, e.g. use-value tax, can target a slower conversion of rural and forestry to developed land (Polyakov and Zhang 2008).

Besides the property tax design, different tax incentives such as preferential tax rates can be offered to encourage energy-efficiency and small-scale renewable energy systems. In the current paper, we study the efficacy of the property tax as an environmental policy tool in the residential sector, aiming to encourage:

- investments in energy efficiency and small scale renewable energy
- sustainable land use

[1] Urban sprawl – "*an expansion of urban development characterised by low density, segregated land use and limited infrastructure provision in more sparsely developed areas*" Brandt, N. (2014). Greening the Property Tax. OECD Working Papers on Fiscal Federalism. OECD Publishing, Paris, OECD. **17**.

[2] Energy sufficiency policies aim to reduce the total energy consumption. Energy sufficiency provides a 'sufficient' level of utility or services from energy, while respecting the limits of environmentally safe operating space. It could concern the changes in daily routines and practices that bring us closer to sufficiency. Thomas, S., J. Thema, L.-A. Brischke, L. Leuser, M. Kopatz and M. Spitzner (2019). "Energy sufficiency policy for residential electricity use and per-capita dwelling size." Energy Efficiency **12**(5): 1123-1149.

There is scarce literature in this regard, and the existing reviews often mix empirical findings on the actual behaviour of landowners with predictions based on numerical simulations. This literature review comprises only ex-post empirical studies of the impact of different property tax regimes. The research design of each study is analysed in detail to evaluate and compare the credibility of the results as some papers that look at similar hypotheses yield contradicting results. The present literature review includes only ex-post analyses that use statistical methods to control for other confounding variables. It does not include papers based on literature reviews (Cansino, Pablo-Romero et al. 2011, Brandt 2014, Shazmin, Sipan et al. 2016), simulations of theoretical property tax models (Turnbull 1988, Bizer 1998, Brueckner and Kim 2003, Muellbauer 2005, Bento, Franco et al. 2006, Cho, Lambert et al. 2010, Cho, Kim et al. 2014, Wu, Mo et al. 2017) or papers using less rigorous methods such as descriptive statistics (Malme 1993, Villca-Pozo and Gonzales-Bustos 2019).

The main challenge for empirical studies is to estimate the true causal effect of the property tax regime on the outcome. There are several obstacles to the identification of the causal effect in observational studies. First of all, the estimate may be biased due to the problem of 'simultaneity' or 'reversed causality'. Property taxation might affect urban sprawl, but at the same time, urban sprawl may also affect the choice of the property tax regime. Urban sprawl often goes hand in hand with a higher demand for public infrastructure. Although it is just one way of financing investments in infrastructure, governments might raise the property tax to fund these additional investments, thereby creating a 'reverse' channel from urban sprawl to property taxation.

A second more general limitation of observational studies compared to experimental studies is the lack of random assignment of the treatment. Random treatment assignment is the best method to get an unbiased estimate of the treatment effect. When units can self-select themselves into treatment, there is always the risk the estimate picks up the effect of unobserved 'confounders', i.e. covariates that are both correlated with the outcome as well as the treatment assignment. Only a handful of studies use statistical methods, such as propensity score matching, or exploit quasi-experimental variation in the treatment to overcome these threats to identification.

Other problems are a lack of focus on the property tax. Most studies regarding investments in renewable energy in the residential sector analyse a wide range of policies in this regard. Moreover, authors often use dummy variables for financial incentives instead of a precise measure. Furthermore, most of the studies comprised in the literature review use data from the US; the external validity of these findings might be limited. Due to these limitations, policy recommendations should be drawn based on a set of studies rather than one study in isolation.

The first section provides an overview of how the property tax can encourage investments in energy efficiency and as a policy to reduce urban sprawl. The overview is based on a literature review and provides a range of levers. Concerning the impact of property tax on energy efficiency, some countries and regions such as Romania and Flanders offer preferential property tax rates for improved energy performance of new constructions. However, there are no empirical studies that explore the effects of these property tax incentives as to our knowledge. The existing studies provide only empirical evidence on the deployment of small-scale renewable systems, and the main findings are gathered in section 2. The first subsection presents evidence showing the efficacy of the property tax incentives in this regard, and subsection 2 presents mixed results or no evidence.

Section 3 summarises findings on the implications of the property tax to urban planning goals. Firstly, the impact of the property tax rates on urban sprawl is investigated, assuming standard property taxation of land and structures. The property tax design itself can have implications for urban development, and the following two subsections detail on other tax regimes such as land value and split-rate tax regimes and their impact on urban sprawl. Lastly, the effects of property tax on changes between land uses are presented. Additional details of the studies included in the literature review can be found in Appendix 1 and 2, such as the statistical model, the variables of the model, details of the property tax design or subsidy, alternative policies analysed, etc. To conclude, a scheme summarises the main findings of the literature review framed as levers to achieve policy goals in the residential sector.

1. PROPERTY TAX AS A LEVER TO STEER SUSTAINABLE BEHAVIOUR

The present section aims to provide an overview of how the property tax can be used to steer sustainable behaviour in the residential sector. The scheme of Figure 1 is based on the review of empirical studies and illustrates what is theoretically possible. The following sections will provide detailed information on which levers are effective and under which circumstances. Property tax can influence decisions of landowners in terms of when, where and how to build. The latter concerns investments in energy efficiency or size, height and building typology. The subsidies to encourage energy efficiency and renewable energy can be of two types: i) reduction of the property rate or ii) exemption of the investment from the taxable base, see Figure 1.

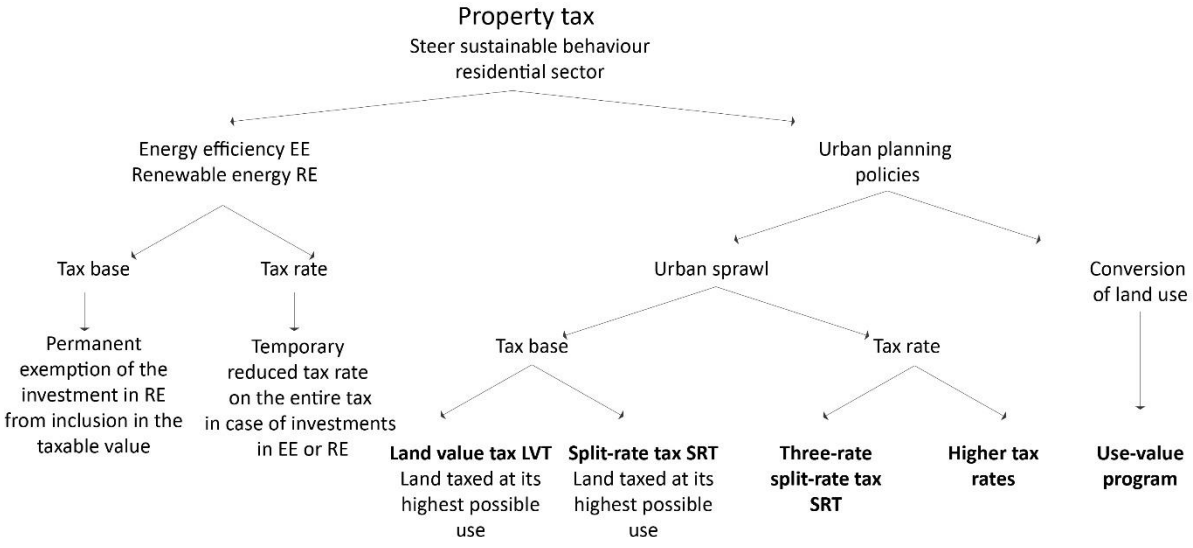

Figure 1 Property tax as a lever to steer sustainable behaviour in the residential sector. Scheme elaborated based on the literature review of empirical studies.

Property tax incentives are not the only method to achieve sustainable policy goals. Property taxation provides useful levers to achieve policy goals such as encouraging or discouraging development or offsetting land use conversion. Strategies to reduce urban sprawl can include discouraging development in the suburbs and encouraging it in the inner city or in areas in proximities to transportation hubs. If the land is taxed at a higher rate than the structure (split-rate tax), then building development can be stimulated or delayed based on how the value of the land is assessed. For example, taxing land at its "highest and best" possible use stipulated by the zoning regulations can theoretically encourage landowners to build sooner and to opt for a higher density building typology. With a standard property tax, where land and structure are taxed equally, the tax rates may play a role in this regard, see Figure 1. On the contrary, a property tax can be neutral if it does not influence the construction decisions of landowners. For example, some municipalities in Finland opted for a two-rate split rate tax, in which the land before and after development is taxed "as if there is no structure on it" (Lyytikäinen 2009). Lastly, certain property tax regimes, such as use-value programs aim to prevent agricultural land to be developed by providing preferential treatment to farmland and other rural lands uses (Polyakov and Zhang 2008). A range of property tax regimes and their impact on urban sprawl and land use conversion will be provided in section 3.

2. PROPERTY TAX AND RENEWABLE ENERGY DEPLOYMENT

This section presents the main empirical findings regarding the efficacy of property tax incentives to encourage small scale renewable energy for the residential sector. Most of the studies regard the deployment of PV systems in the US and only one study regards the solar thermal technologies in Spain. Few studies focus only on the property tax incentives, many consider a wide range of policies in this regard, such as other financial incentives, command-and-control policies and other support policies.

A limitation of some of these studies is the use of dummy variables for financial incentives, failing to assess their magnitude. Therefore, the research design does not allow us to conclude strongly on the relationship between the property taxation and the deployment of renewables in the residential sector. Nevertheless, even though each study in isolation is not sufficiently robust, the studies provide evidence supporting each other. The section is structured in studies that provide evidence of a positive impact and those that show no impact or mixed results.

2.1 Positive impact

One of the studies that analysed the impact of property tax reduction on deployment of solar thermal technologies in Andalusia, Spain is (Sánchez-Braza and Pablo-Romero 2014)[3]. The tax subsidy consisted of a reduction of up to 50% of the property tax rate for a period of 1 to 3 years in the case of

[3] See Appendix 1 Studies property tax and renewable energy deployment and Appendix 2 Studies property tax and sustainable energy use for more details regarding the studies.

investments in solar thermal systems. The incentive excluded new constructions because the Technical Building Code requires the solar thermal system to cover 30% to 70% of domestic hot water demand.

The study used propensity score matching to address the non-random allocation of the treatment in the observational data set. Propensity score matching is a technique through which researchers try to make the treatment and control group comparable in terms of possible confounders. In this case, the municipalities from Andalusia that adopted the property tax reduction were considered the treatment group. Other control variables such as population, rural, liberal voters, etc. were included in the model. The dependent variable was the number of square meters of solar systems installed in the specific municipality.

The property tax reduction in Andalusia has a significant positive effect on promoting solar thermal installations on buildings. The municipalities who applied the tax reduction experience a relative increase of 41% to 45%, while the municipalities who did not apply the tax bonus would have had a relative increase of 71% to 98% if they had implemented the measure. The authors suggest that the good results of the policy measure may be associated with the high visibility of the property tax and that the financial incentive would allow to consider the installation to be profitable.

Another study that found a positive impact of property tax reduction in the deployment of renewable energy is the study from Li and Yi (2014). In this case it regarded PV technologies in the US. The property tax subsidy was studied as part of state incentives alongside sales tax, corporate income tax and personal income tax. Besides state incentives, property tax subsidies were analysed also as part of local incentives – property tax abatements and property tax credits, alongside rebates, direct grants, direct loans, feed-in tariffs and sales tax credits. The model uses dummy variables, if any local incentive is provided, then the variable equals 1 in the model, with the limitation of ignoring the size of the subsidy. Other local policies under study were educational programs, expedited permitting process and local solar goals, while state policies included renewable portfolio standard regulations and solar carve-outs.

The dependent variable of the regression analyses was the solar PV capacity installed in cities, while control variables included solar radiation, education level, population, fiscal health of the municipality, etc. Results show that local level financial incentives (including property tax abatements and property tax credits) are significant for the deployment of PV, alongside state level obligations to utilities. Yet, state level financial incentives are not significant.

2.2 Mixed results and no impact

The following studies show mixed results or no impact of the property tax incentives on deployment of residential renewable energy.

(Shrimali and Jenner 2013) analysed the impact of 12 state-level policies, including property tax incentives on cost and deployment of PV systems in 16 states in the US in both the residential sector and the commercial sector. The policies under study included financial incentives (property tax incentives, cash incentives, income tax incentives and sales tax incentives); command-and-control policies (standards, mandatory utility green power options and state government green power

purchasing) and support policies (contractor licensing, equipment certification, solar access, net metering, and interconnection standards).

All policies were coded as binary variables in the model that has the limitation of not considering the size of the incentive. The model included five economic and political control variables, a state fixed-effects dummy variable and a vector of year dummy variable that controls for national trends. The first dependent variable was the deployment of PV systems expressed in annual installed capacity in MW in the residential, commercial, and utility sector, respectively. The second dependent variable was the cost of the PV systems represented as balance-of-system (BOS) i.e. the "*pre-incentive difference between the total system cost and module costs*". The total cost includes all hardware costs (module costs and non-module costs such as inverters, transformers, cabling, racks, etc.) and all soft costs such as installation and transactional costs.

The property tax incentive under study was the exemption of the solar system from the taxable value of the property, which could be a less salient incentive compared to the reduction of the property tax rate operated in Andalusia in the study of (Sánchez-Braza and Pablo-Romero 2014). Another difference between the two subsidies could be the magnitude of the reduction.

The results confirm the initial hypothesis of the study that property tax incentives would foster deployment of systems in the commercial sector and reduce cost, contributing to making PV technologies more competitive on the market relative to other technologies. Yet, the authors point out the surprising finding that in spite of the cost reduction, the property tax incentive did not contribute to deployment of PV technologies in the residential sector. This finding can be explained with characteristics of the property tax incentive such as "*indirect impact and second-order effect that requires financial and information sophistication*" (Shrimali and Jenner 2013) since the property tax incentive is operated through a reduction of the tax base.

A similar study (Sarzynski, Larrieu et al. 2012) compared the efficacy of state-level incentives on deployment of PV technologies in the US. As in the previous study, the property tax incentive was considered amongst other state financial incentives and consisted in not including the value of solar installation in the assessment of the taxable property value. Yet, in this case no distinction was made between residential and commercial PV installations.

The study uses a time-series cross-sectional (TSCS) fixed effects model that uses differences-in-differences approaches. The dependent variable of the model was the annual amount of solar technologies installed (annual amount of grid-tied PV capacity installed in a state in kW). Explanatory variables were state level financial incentives including property tax, income tax, sales tax and cash incentives (rebates or grants). Similarly to (Shrimali and Jenner 2013), the incentives were modelled as binary variables, ignoring differences in size of the subsidy. According to the authors, states offer subsidies that vary strongly in magnitude, as well as in "*function, type, method used to calculate incentive value, maximum incentive value, eligible technology, or sectors that may claim the incentive*". Control variables comprised other state policies (renewable portfolio standards and net-metering), electricity prices, per capita GDP, population, time fixed-effects to account for other variables such as federal income tax credit. The latter is a subsidy that does not vary across states.

Results show that cash incentives (rebates or grants) are effective, while property tax and sales tax incentives appear to be insufficient to spur the PV market. States that provided cash incentives had a

248% higher amount of PV installed on average. According to the authors, income tax incentives should function as cash incentives, if combined with the federal income tax credit, yet their effect is not significant. In this case cash incentives are more effective compared to tax incentives because they "*tend to be simple in design, easy to claim and large in value*" (Sarzynski, Larrieu et al. 2012). The property tax incentive is structured as avoiding a penalty, an increase in the taxable base. Whereas a simpler way of avoiding this penalty is not investing in PV systems in the first place. Another reason could be that the cash incentives ease the load of upfront investment needed or that homeowners have high discount rates. Yet, we cannot conclude that cash incentives are more effective than any type of property tax incentives since in this case only a certain type of property tax incentive was analysed.

These findings are confirmed by the study of (Matisoff and Johnson 2017). As in the previous paper, the impact of various policy measures to promote new PV installations was compared, in this case limited to the residential sector. While the previous studies used dummy variables for incentives, the innovative aspect of the study is the monetisation of the 400 state and utility incentives that allowed their aggregation and comparison. According to the authors, standard decision theory suggests that consumers consider only the total value of incentives and that the type of the incentive should not matter. Yet, based on previous empirical evidence, the study hypothesised a different response depending on the design of the policy measure and aimed to understand the role of incentive salience on consumer behaviour. In the US there are three commonly used property tax incentive: i) solar system installation is not accounted for in the valuation of the taxable property for a fixed number of years or until the property is sold, ii) a reduction in the property tax rate and iii) a dollar per W or per kWh type of incentive. A limitation of the study is that only the third type of property tax incentive was considered because of the difficulty to monetise the other two types.

The dependent variable was the state-level data on residential PV installations from 2002 to 2012 in the US. Explanatory variables were local and state incentives, namely direct cash incentives (rebates, buy downs, grants and performance-based incentives), property tax incentives (exemptions, abatements, tax credits and special assessments), sales tax incentives (exemption and refund from sales tax), tax credits and renewable portfolio standards. Other policies included in the model but not quantified in monetary terms were net metering and governmental subsidised financing.

The results of the regression analysis show that only direct cash incentives appear to be effective and only when coupled with financing initiatives and net metering. The magnitude of the effect is much higher when financing availability is in place - with every dollar per W of cash incentive leading to an additional 6.5 kW of capacity additions per 1000 customers. Property tax reduction, amongst other tax reduction does not appear to alter residential PV installation. According to the authors, property tax benefits might not be salient enough because the property tax is usually paid in a bundle with insurance and mortgage. In general tax incentives are ineffective in comparison to immediate cash incentives because they are delivered over a long period of time and require an administrative burden. The magnitude of the property tax incentive is 0.03 dollar out of the average total incentive of 0.91 dollar. According to the estimations of the authors approximately 67% of the total budget were likely spent on incentives that did not increase residential solar PV installations. Results show that a mix of policies is more likely to be successful, such as cash incentive with support policies of financing and net metering.

3. PROPERTY TAX AND SUSTAINABLE URBAN PLANNING POLICIES

In the following subsections, we discuss studies that looked at the impact of property taxation on urban sprawl. The first subsection explores the impact of different tax rates of a standard property taxation on the size of the urban areas, on the density as well as impact at building scale in terms of building typology or the size of the plot. The standard property tax regime taxes both the value of the land and the value of the structure at the same rate, while at the same time different levels of administrations can opt for different tax rates.

Theoretically, the increase of a standard property tax rates can have the two opposite effects on the urban sprawl the *improvement effect* and the *dwelling size effect* (Pollock and Shoup 1977, Banzhaf and Lavery 2010, Wassmer 2016). The improvement effect anticipates that higher property tax rate would decrease the amount of structure more than the amount of land because the supply of structure is price-elastic and thus would encourage less multi-storey units (Wassmer 2016). Less structure on an equal amount of land implies a lower structure-to-land ratio or structural density, thus would contribute to urban sprawl. This effect is referred as the *improvement effect* in the literature (Pollock and Shoup 1977, Banzhaf and Lavery 2010, Wassmer 2016). On the other hand, the *dwelling size effect* can mitigate the improvement effect. The property tax could decrease urban sprawl because consumers might choose to build smaller houses on smaller lots (Wassmer 2016). Whether property taxation increases or decreases urban sprawl is thus essentially an empirical question. The results of the empirical studies presented in the subsection "*Property tax rates and urban sprawl*" will provide insights on which of these two effects prevail.

The second and third subsections explore the implications of different property tax regimes on reducing urban sprawl, namely the land value tax and the split-rate property tax. The land value tax is levied only on the value of the plot of land without considering the value of improvements built on it (Wenner 2018). In the EU only one country, Estonia has opted for a pure tax on land (Wenner 2018) and its effects on urban development and urban sprawl will be presented in subsection *"Taxing land but not the structure".*

Yet, because not taxing capital improvements may not be equitable, many countries opted for a compromise option i.e. the split-rate tax. A split-rate property tax taxes both land and improvements but at different rates, with more weight put on land (Banzhaf and Lavery 2010). Compared to the traditional property tax on structures, split-rate tax is considered less distorting and can be used to steer decisions of landowners. It can discourage or encourage the development of the plot if the value of the land is calculated at its current use, or at its "highest and best possible use" (Oates and Schwab 1997). The subsection *"Taxing land at higher rate than structure"* presents empirical findings on how different tax regimes of the split-rate tax can steer behaviour of landowners in terms of what, when and how they build.

3.1. Taxing land and structure at the same rate

Property tax rates and urban sprawl

The study by (Song and Zenou 2006) investigated the effect of different levels of property tax rates on the size of 448 urban areas in the US. The hypothesis of the study was that an increase in the rates decreases urban sprawl. The authors estimated the area of different tax jurisdictions using GIS (Geographic Information System) methods within urbanised areas, followed by computing weighted average for estimating the tax rate for each of the 448 urbanised areas. The size of the urban areas was then regressed on the property tax rates controlling for population, income, agricultural land rent and commuting cost. The explanatory and dependent variables may be affected by simultaneity bias - urban sprawl might have an effect on the property tax rate because the larger demand for infrastructure, which goes hand in hand with sprawl, requires more funding. To address the simultaneity, Song and Zenou used the magnitude of state aid to schools as an instrument for the property tax rate in a two-stage least squares (2SLS) regression.

The coefficient estimate on the property tax rate is negative and statistically significant, implying that urbanised areas with a higher level of property taxation are smaller in size. In order to evaluate the magnitude of the effect, the authors compare it with the coefficient estimate on the population variable. A 1% increase in population is associated with 0.52% increase in the size of the urban area, while a 1% increase in the property tax rate reduces the urban spatial extent by 0.4%. Their result thus suggests that property taxation reduces urban sprawl. A limitation pointed out by (Wassmer 2016) is the use of statutory tax rates instead of effective tax rates. The former are the rates of jurisdictions while the latter account for exemptions that occur in practice for homeowners and are calculated from actual taxation data.

A similar study of (Wassmer 2016), investigated the impact of property tax rates on urban sprawl in 370 urbanised areas in the US. While some studies use the statutory property tax rates in their analysis, Wassmer computed the effective rates. The research question was whether effective rates of residential property tax affect the size of the urbanised area after holding population constant. The first hypothesis took into account the improvement effect that anticipates a negative effect on capital intensity and therefore greater urban sprawl. The second hypothesis was based on the dwelling size effect anticipating that higher property tax rates might encourage landowners to build smaller houses on smaller lots. This positive impact would translate into less urban sprawl. The aim of the study was to provide evidence on which of the two hypothesised effects prevails.

The dependent variable of the regression was the natural log of square miles of land of urbanised area that reflects urban sprawl. Explanatory variables were population of the urbanised area and the effective property tax rate proxied by 3 variables – the property tax rate for a median value of a single-family home, the property tax rate for a single-family home with 150,000$ market value and property tax rate for a 600,000$ market value rental apartment. Control variables included resident housing preferences, development constraints, commuting costs, urban fringe land cost, murder rates in the city centre, economic factors, local fiscal structure, preferential property tax treatment and urban area fixed effects.

Surprisingly, the results show an opposite effect compared to the study of (Song and Zenou 2006). A one-standard deviation increase of the effective tax rate over the decade is associated with an increase in the size of an urbanised area of 2% to 4% for a given level of population. The results of Wassmer suggest that a rise in the property tax rate increases the amount of land used for a given population, which implies greater urban sprawl – higher property tax rates encouraged more one-story units with lower population density. The improvement effect does not seem to be countervailed by the dwelling size effect.

Since these results provide evidence that higher property tax rates increase urban sprawl, the author suggests a reduction in reliance on the standard property taxation i.e. the same tax rate applied to both the structure and the land value. He refers to a split-rate property tax that taxes more heavily the land compared to structures, as an alternative tax regime. Yet, a limitation of the study is that it did not consider the differences in tax regimes of the urbanised areas, since certain administrations in the US adopted the split-rate tax regime. The implications of land value tax and split-rate tax on urban development is detailed in the following subsections.

The previous studies analysed the impact of the property tax rates on the size of the urban areas. The study of (Lutz 2015) assesses their effect on residential construction activity – the study analysed the impact of a school finance reform in the state of New Hampshire, the US. Due to a Supreme Court sentence that found the funding of primary education from the local property tax unconstitutional, the state issued large grants to some municipalities. The grants which were used to fund property tax reduction resulted in a tax shock. This unusual tax reform allows to study the relationship between property taxation and new home construction, without affecting the public services funded by the tax. Yet, these findings cannot be transposed to other contexts where the property tax rates are associated with provision of public services and infrastructure.

The research question was whether the location of residential development is affected by the property tax. The study regarded only new single-family dwellings, thereby ignoring other denser building typologies such as multi-storey buildings and thus the potential improvement effect of the property tax. The dependent variables of the model were i) residential investment, computed as the number of single-family home building permits divided by the stock of existing single-family homes and ii) house prices measured as the mean sales value of existing homes in a municipality. The initial grant in 1999 relative to the total property tax payments in 1998 is used as a measure for the size of the fiscal shock. Lutz argues that this measure is a good proxy for the fiscal shocks in later periods given the small changes in the grants. Other control variables of the model were municipal and year fixed-effects to account for time-invariant municipal-level and state-wide time-varying differences in building activity.

The results show that communities with a reduced tax burden experience a substantial increase in residential construction – a community receiving the mean grant of 15% of pre-reform local property tax revenue experiences an 11-22% increase in residential investment. Yet, results differ in the area within 15 miles from Boston due to differing housing supply elasticities in the suburban ring relative to the rest of the state. In the suburban area the shock of the tax reform is cancelled through a price adjustment i.e. by capitalising into property values. At the same time, according to the author, communities that witnessed an increase in the building activity because of the decrease in property tax burdens, adopted stricter regulations that will likely slow the growth in the supply in the future.

While the previous paper analysed the impact of the property tax rates on the extensive margin of residential investment, i.e. the number of permits for single family houses, (England, Zhao et al. 2013) investigated the intensive margin of investment. Specifically, the authors analysed whether property tax rates affect the design of single-family houses in terms of i) lot size, ii) living space and iii) building height. The sample of houses under analysis was limited to newly built single-family houses in 41 towns and cities in New Hampshire, US. The hypothesis of the study was that dwelling size effect would prevail and an increase in property tax rates would reduce lot size, living space and building height.

The explanatory variables of the regression analyses were property tax rates, public expenditure on local services (expressed as real per pupil expenditure on elementary public schools), zoning regulations, location characteristics and local economic conditions. As previously mentioned, the dependent variables were lot size, living area and building height of newly constructed single-family homes. Control variables were provision of water and sewerage services, year dummies in order to control for time effects and county variable to capture unobserved heterogeneity across counties.

Results show that higher property tax rates are associated with both smaller lots and smaller houses, i.e. fewer stories and less living space. However, the location plays an important role. The design of new residential properties is less sensitive to property taxation in communities closer to Boston, but the effect of the property tax rates is still significant. In these municipalities a 10% increase in the property tax rate would be associated with a 1.6% decline in living space and a 2.4% decrease in lot size. In comparison with the communities closer to Boston, northern towns and cities experience a 1.8% decrease in living area and a 4.3% decrease in lot size with an increase of 10% in the property tax rate. Similar differences in supply elasticities between the suburban area and the rest of the state were detected by (Lutz 2015).

It is important to underline that the sample consists only of single-family buildings, therefore in this case lower height and smaller living space would contribute to a smaller amount of living area per person and therefore it is a positive aspect in terms of sufficiency. Even though single-family developments have a low density compared to multi-family dwellings, smaller lot sizes imply higher density of building units per square mile within single-family typology. Therefore, a limitation of the study is not including in the sample multi-family dwellings, where increased living space and building height could imply a higher number and density of units. Another limitation according to the authors is that the delay in the decision to build was not part of the study since some landowners could decide not to develop the land at all, or postpone the development.

Institutional setting, property taxation and urban sprawl

While the previous studies analysed explicitly the relation between property tax rates and urban sprawl, (Ehrlich, Hilber et al. 2018) studied the relation between institutional setting, such as decentralisation and urban sprawl. Decentralisation implies differences in both land use policies and fiscal incentives (including property tax). The study compared 36 European countries. The hypothesis was that more decentralised countries are characterised by more dispersed residential development.

Regressions used the index of dispersion of residential settlements as dependent variable, which was computed from high resolution satellite imagery and served as a proxy for urban sprawl. Institutional

setup, i.e. the degree of decentralisation affects both planning and fiscal policies. Explanatory variables reflecting decentralisation were subnational autonomy, federal constitution, number of levels of government and regional autonomy index that summarises different dimensions of decentralisation. Control variables included the logarithm of GDP per-capita and a dummy variable for Central and Eastern European Countries since these countries display a higher degree of urban sprawl.

The empirical findings confirm the hypothesis – institutional factors are important in determining urban sprawl since decentralisation and the number of municipalities are significantly positively correlated with urban sprawl. The magnitude of the effect is quite high, decentralised countries have a 25-30% higher sprawl index compared to centralised ones. Yet, from the design of the study it cannot be determined whether the effect is due to differences in land use policies or fiscal incentives. According to the authors, local governments of centralised countries lack sufficient fiscal incentives (such as property tax incentives) to encourage residential development. This contributes to making housing supply inelastic and causes housing shortages and increase in prices. There is a trade-off between urban containment and house affordability policies, since urban sprawl is significantly negatively correlated with the growth of real estate prices. Countries that allow residential development outside urban areas have lower house prices compared to countries with strict containment policies such as green belts in the UK.

3.2. Taxing land but not the structure

Even though the benefits of land taxation are commonly acknowledged in literature from a theoretical point of view, there is little evidence from ex-post analyses since countries usually opt for a split-rate tax instead of a pure tax on land value. The only exception in Europe is Estonia which adopted a land value tax in 1993. (Wenner 2018) studied the effect of the land value tax on urban development patterns to see whether it can act as a tool against urban sprawl. The value of the land reflects the highest possible use of the land allowed by zoning regulations, not the current land use. It is important to note that the tax rate in most locations is quite low at 1% of land value and that exemptions are awarded for owner-occupiers since 2012.

Lacking variation within Estonia itself, the study tries to assess the impact of the land value tax by comparing residential construction in Tallinn to that in Riga, the capital of Lithuania, which has a standard property tax. The hypothesis of the study is that land value tax reduces urban sprawl in the suburban areas and increases building density in the inner city of Tallinn. Variables used as proxies for a compact city were population density, residential building density and residential buildings construction. The study investigated the impact of the land value tax with regard to density at three different scales:

1) Macro level – large-scale suburbanisation processes.
2) Meso level – differentiation between core city and inner metropolitan area.
3) Micro level – whether inner-city processes of densification take into account suburbanisation processes within city boundaries.

The descriptive analysis shows that the capital-land-ratio and population density increases more strongly in Tallinn compared to Riga. Since the study did not use any statistical method to control for other confounding variables, the differences in trends between the two cities can arguably be

considered as the causal effect of the policy. According to the author, the differences might be due to the prospering and growing Tallinn region in general rather than the land value tax. Nevertheless, both cities show considerable suburbanisation and sprawl since the relative growth of floor space to area of municipality was even stronger in the suburbs.

3.3. Taxing land at a higher rate than structure

Land value taxation described in the previous subsection eliminates the taxation on structures. It is considered to be less distorting than the standard property tax and more likely to reduce incentives for cities to sprawl (Banzhaf and Lavery 2010). Yet, not taxing capital improvements at all may not be equitable, therefore a split-rate tax is a compromise that applies a lower tax rate on structures than on land. An important aspect of the split-rate tax to consider when interpreting the results is whether land is taxed according to its current use or to its "highest and best" possible use. Split-rate tax on the "highest and best" possible use could stimulate construction by encouraging earlier development of unused parcels. This subsection summarises the main findings supporting the hypothesis that split-rate tax could be a useful tool against urban sprawl.

The paper of (Oates and Schwab 1997) explores the effects of split-rate tax on building activity. Specifically, it studies the impact of the tax reform in Pittsburgh in comparison with other 14 cities in the region. The tax reform consisted in increased rate on land compared to structures. The difference in rate of 5 times is not only a result of increasing the rate at which land is taxed, but also due to tax subsidies for structure such as property tax abatements for new construction. The city did not tax the value from new construction for the first 3 years that equals to a magnitude of approximately 1.5% subsidy (reduction in price) for the new construction.

The dependent variable of the regression model was the average annual number of building permits, which are split along two dimensions: i) residential versus non-residential buildings and ii) inner city versus suburb. Other economic conditions were controlled for such as office demand.

Following the change in the tax regime, Pittsburgh experienced an increase in its building activity, both in the commercial as the residential sector, but the increase was only modest in the latter. The boom in the commercial sector could have been caused by an increase in demand for office space after the transformation of the economy from manufacturing to service-oriented. Yet, cities with similar vacancy rates for office buildings did not experience similar growth. Even after controlling for demand factors, the effect of the change in the tax regime remains large and statistically significant in the commercial sector.

Yet, we cannot conclude that the split-rate tax in itself is capable of generating major building activity since the tax reform coincided with a strong demand for office space and other policies for urban renewal. At the same time, the authors assume that the reliance on revenues from increased land taxation could have played a role in the increase in the building activity by enabling the city to avoid increases in other taxes that could have impeded development. A second limitation of the study of (Oates and Schwab 1997), mentioned in (Banzhaf and Lavery 2010), is that the use of buildings permits as dependent variable does not allow to disentangle the improvement effect from the size effect since permits can also account for additions to existing buildings. Even though urban sprawl was not part of the study, these findings could be useful for sustainable urban development. Increased building activity

is positive in certain locations, for example in the inner cities and in proximity to the transportation hubs.

The study of (Banzhaf and Lavery 2010) analysed the impact of the split-rate tax on urban sprawl by comparing jurisdictions in Pennsylvania that have adopted split-rate tax with the ones that did not. The innovative aspect of the study was the distinction made in the improvement rate (capital/land ratio) between the density and the dwelling size effects. The dependent variable was the number of rooms per square mile and served as a proxy for the structure-to-land ratio. Banzhaf and Lavery then analysed to what extent the change, if any, in the structure-to-land ratio is driven by a change in the average number of rooms per housing unit i.e. a proxy for dwelling size, or by a change in the number of housing units per square mile i.e. the proxy for density. Banzhaf and Lavery apply a difference-in-differences strategy by comparing the change in the trends in development for census tracts which adopted a split-rate tax with tracts that kept a single rate regime.

In a first analysis they control for other census tract characteristics directly by including them in the linear regression model. In a second analysis, they use the propensity score to match split-rate census tracts to similar control tracts. In order to control for other factors due to geographical location, the model included a location vector in terms of degree latitude and longitude.

The results show that the adoption of a split rate regime leads to 'smarter growth'[4] patterns, it increases the capital/land ratio, the total number of rooms per square mile increases with approximately 5% to 6% points relative to the control tracts. This result suggests that shifting the tax burden from structure to land raises the structure-to-land ratio. According to the authors, the effect is more housing units rather than bigger units. Another aspect that should be taken into account is the building typology. Theoretically, the split-rate tax could encourage development of low density detached housing by subdividing parcels into smaller lots. In the case study of Pennsylvania, the results show that split-rate tax did not encourage the construction of detached houses, but appears to increase the construction of high-density structures with 5 and more dwelling units.

Yet, these results do not show that split-rate tax has resulted in less sprawl but that split-rate tax appears to be an effective tool to increase density in certain locations. According to the authors, "*If* split-rate tax *is applied in exurbs or rural areas, any resulting increase in density would mean an increase in urban sprawl.* Split-rate tax *is a toolkit for urban planners that should be used in the right time and place*" (Banzhaf and Lavery 2010). It would be therefore useful to apply split-rate tax regimes to areas in the proximity of transportation hubs or public services.

Another type of split-rate tax reform was introduced in Finland in 2001 that allowed municipalities to tax undeveloped land at a higher rate than developed land. The effects of this reform on residential development were analysed empirically by (Lyytikäinen 2009). The municipalities that adopted the tax reform had a three-rate property tax with different tax rates on land before development, on land after development and on buildings. Other municipalities kept the previous two-rate system – uniform land tax and a building tax.

[4] Smart growth is an urban planning theory advocating for compact urban development in urban centres to void urban sprawl by encouraging infill constructions and development of communities.

The hypothesis of the study was that the larger difference between the pre and post-development land tax of the three-rate property tax encourages building development. The two-rate system land tax is theoretically neutral, since the taxable value of land does not depend on the landowner's actions. With the two-rate system the post-development taxable value of the land was defined as "*what the site would be worth if there were no structures on it*. The three-rate system, with its preferential tax treatment for developed land, breaks this neutrality.

The study estimated the effect of a three-rate tax system on the number of housing starts and on the development density, measured as the volume (in cubic meters) per start. However, such a proxy for density ignores the size of the plot. Housing starts were regressed on the difference between the pre- and post-development land taxes. The author analysed all housing starts and the starts of single family housing separately. Control variables included housing prices, housing stock per capita, province level year effects and common quarter dummies. A limitation of the study according to the authors is that the results may partly reflect the market conditions.

The empirical results confirm the initial hypotheses of the study – taxing undeveloped land at a higher rate than developed land has a positive effect on housing starts, with a greater extent for single-family starts. Municipalities that adopted the three-rate property tax system had an increase in single-family housing starts of 12%. A 1% point increase in the pre-development tax rate is associated with an increase in single-family housing starts of 5.5%. The price elasticity of housing starts is 1.13 for single-family starts and 0.58 for all starts. According to the author, single-family starts are more responsive to tax incentives than larger units because the former are more affected by land taxes and because multi-family housing might include social housing. The results show that the two-rate system property tax is a neutral land tax. The results clearly show that landowners respond to the tax incentives and that the three-rate property tax stimulates residential development, yet there is the risk of low-density constructions such as single-family units.

3.4. Property tax and land use

Previous studies investigated the impact of the property tax on construction activity and urban sprawl. The present subsection focuses on the property tax as a lever to offset land-use conversion. Specific property tax regimes such as use-value program aim to prevent the development of rural land and forestry. Containing the development of land aims to prevent soil sealing and preserve permeable soil. Urban development of rural land is irreversible or very difficult, slow and costly to reverse (Bimonte and Stabile 2015). Land use is regulated by zoning, yet, the decision of landowners to develop the land that is possible according to the zoning can be offset or encouraged with financial incentives such as preferential property taxation.

(Polyakov and Zhang 2008) analysed the effect of the use-value program in Louisiana, the US, on land-use changes between agricultural, forestry, developed, and Conservation Reserve Program. The use-value program provides substantial tax relief to landowners and allows preferential property tax treatment of farmland and other rural lands. Agricultural and timberlands were assessed at 10% of use value, and other lands were assessed at 10% of fair market value. According to the study's hypothesis, taxing a particular land use at a higher rate decreases the probability of land being retained in or converted to this land use.

The study compared property tax and land-use conversion over five years of 13,414 plots with a total of 22.6 million acres. The random parameters logit (RPL) model was used to model transition between four land uses over a time interval, which allowed "*to model complex substitution patterns among land uses, overcome independence of irrelevant alternatives and correlation of unobserved components of utility for individual plots over time*" (Polyakov and Zhang 2008). The dependent variable of the model was the choice of land use at the end of a five-year period, which is a function of the variable at the beginning of the period. The explanatory variable is the property taxes per acre for different land uses. Control variables included plot-level land quality, per acre agricultural returns, forestry returns, returns of developed lands, effects of population and proximity to populated places.

The results show that land-use transition probabilities are inelastic with respect to property tax, therefore the current use-value program appears to be ineffective to prevent land conversion. According to the simulations, removing the current use-value system would increase developed land but only with a magnitude of 0.2%, while it would increase the surface of forest lands with 1.3%.

(Ferguson and Spinelli 1998) studied the same effect of the use-value taxation program on delaying land use conversion but over a period of 50 years. Cities and counties of Virginia had the freedom to adopt use-value taxation and 57% of them adhered, which allowed the estimation of the effect before and after the adoption of the tax reform. As in the case of Louisiana (Polyakov and Zhang 2008), the use-value taxation in Virginia offered tax incentives or relief programs in order to offset urbanisation pressures and delay the conversion of rural land. According to the hypothesis, the census data would show less conversion than predicted from the historic data (prior the adoption of use-value programs), therefore the tax reform would slow conversion of farmland to non-farm use.

The time-series analysis chosen allows to test the differences between predicted and actual loss of farmland. The year is the predictor variable of the model and farm acreage percentage is the dependent variable. A limitation of the study is focusing only on rural and developed land without considering other land uses such as forestry and land under the Conservation Reserve Program. The results do not confirm the hypothesis in any of the study locations, as no correlation could be verified between the introduction of use-value taxation and a slower rate of farmland conversion. Moreover, the tax reform not only failed to decrease but even increased the conversion of farmland in two occasions in Prince William County. According to the authors, lack of effectiveness of the use-value program might have another negative consequence. Authorities at local and state level did not study or implement any other policy for sustainable land use such as rewarding developers for fill-in development on smaller vacant parcels.

4. CONCLUSIONS

The main findings of the literature review are summarised in Figure 2, translated into levers for achieving different policy goals. To assess the effectiveness of the property tax to steer sustainable behaviour, we have to consider in detail which tax regime was applied or the structure of the tax incentive. There are important aspects such as whether the land, the structure or both are taxed, how the value of the land is estimated (current use or 'highest and best' possible use), whether the tax

reduction or tax exemption is implemented in the tax rate or tax base. All these aspects, among others, can work as levers for different policy goals. Tax regimes can influence landowners' decisions on when, where to build or even how to build in terms of size, density, building typology and height.

Tax regimes that tax only the land (land value tax) or tax land at a higher rate than structures (split-rate tax) are effective against urban sprawl because they encourage higher density developments. Their effect proves to be more housing units rather than bigger units. A key aspect is the location of the policy intervention. Often studies explored the use of the property tax as a tool to encourage building activity. This aspect could be useful for urban planning policies for increasing population and building density in the inner cities (infill strategies) and proximity to the transportation hubs.

The impact of property tax rates of standard taxation – in which both land and structure are taxed on urban sprawl is theoretically ambiguous. There are two effects that work in the opposite direction and might cancel each other out. On the one hand, higher property tax rates can lower the demand for structure, which is called the 'improvement effect' (Wassmer 2016). Lower demand for structure might lead to a lower degree of structural or capital intensity, for example, less multi-storey buildings. All other factors, like population and dwelling size kept equal; a lower degree of structural intensity implies a lower population density and higher urban sprawl. On the other hand, the 'dwelling size effect' predicts the opposite; higher property tax rates can reduce urban sprawl with landowners choosing to build smaller houses on smaller lots (Wassmer 2016).

Empirical findings of ex-post studies were analysed to look for evidence on which of the two effects prevails. Unfortunately, there are no conclusive findings since studies show that higher property tax rates contribute to greater sprawl when the improvement effect prevails (Wassmer 2016) and the opposite when the size effect dominates (Song and Zenou 2006, England, Zhao et al. 2013). The main difference is that (Wassmer 2016) and (Song and Zenou 2006) studied the spatial extent of urbanised areas while (England, Zhao et al. 2013) analysed only the deployment of single-family typology. Their results imply that higher tax rates contribute to smaller lots and higher density only within a single-family typology, while in the case of multi-family buildings, it could mean a lower density of living units per m^2 and, therefore, higher urban sprawl.

Residential development can have negative environmental impacts such as degraded biodiversity and flooding risk because of increased sealed surfaces (Polyakov and Zhang 2008). Once the land is converted to more intensive uses such as urban development, its conversion is permanent or difficult and expensive to reverse (Bimonte and Stabile 2015). Land use is regulated by zoning, yet, the decision of landowners to develop the land can be offset or encouraged with financial incentives such as preferential property taxation. The use-value tax regime aims to prevent the conversion of forestry, and agricultural land to more intensive land uses such as developed land, but the empirical studies showed that their effect is not significant (Ferguson and Spinelli 1998) (Polyakov and Zhang 2008). A possible explanation is that the property tax incentives are very low compared to the financial benefits resulting from developing the land.

The impact of property taxation on urban development is also analysed from the point of view of the institutional setting. Decentralisation affects the competition between municipalities and gives them leverages for fiscal policies such as property tax incentives. Municipalities might use property tax to encourage building activity since they rely on the property tax for revenues and might be more

permissive on urban containment policies against urban sprawl, such as green belts and preservation policies for undeveloped land. Besides, there is a trade-off between urban sprawl containment and housing prices. For these reasons, (Ehrlich, Hilber et al. 2018) and (Bimonte and Stabile 2015) question whether fiscal policies, such as property tax and urban planning policies, should remain at the same institutional level.

If more studies explore the property tax as leverage for urban planning policies, the implications to energy efficiency policies are less investigated. Even though some countries such as the US, Spain, Belgium, Romania and Italy offer property tax incentives in this regard, few studies offer empirical evidence of their efficacy. To the authors' knowledge, all the studies regard the deployment of small-scale renewable energy systems in the residential sector, even though some property tax incentives, for example, in Flanders and Romania, are offered if a certain energy performance level is achieved. For solar systems, the property tax reduction can be implemented as a discount of the property tax rate (Spain) or as an exemption of the system from the taxable property value (the US). In the latter case, the property tax incentive might be smaller in size, less salient, too sophisticated for the residential sector and avoiding a penalty may be less of an incentive. In fact, this implementation of the property tax incentive in the tax base was not effective for PV systems in the residential sector (Sarzynski, Larrieu et al. 2012, Shrimali and Jenner 2013). Providing a property tax reduction in the tax rate has increased the deployment of solar thermal (Sánchez-Braza and Pablo-Romero 2014) and PV systems (Li and Yi 2014).

Conclusively, it can be stated that the literature review provides evidence that specific property tax regimes can be effective in steering behaviour, especially as a tool against urban sprawl. According to Wenner, "*real estate taxation is a possible yet underused setscrew for targeted urban development policies*" (Wenner 2018). Regarding renewable energy systems, the comparison between incentives has shown that the design of the incentive plays a role in its effectiveness and a mix of policies is more likely to be successful (Matisoff and Johnson 2017). Figure 2 summarises the main findings of the literature review and provides guidelines on which property tax regime is more suitable in achieving a specific policy goal in terms of sustainability in the residential sector.

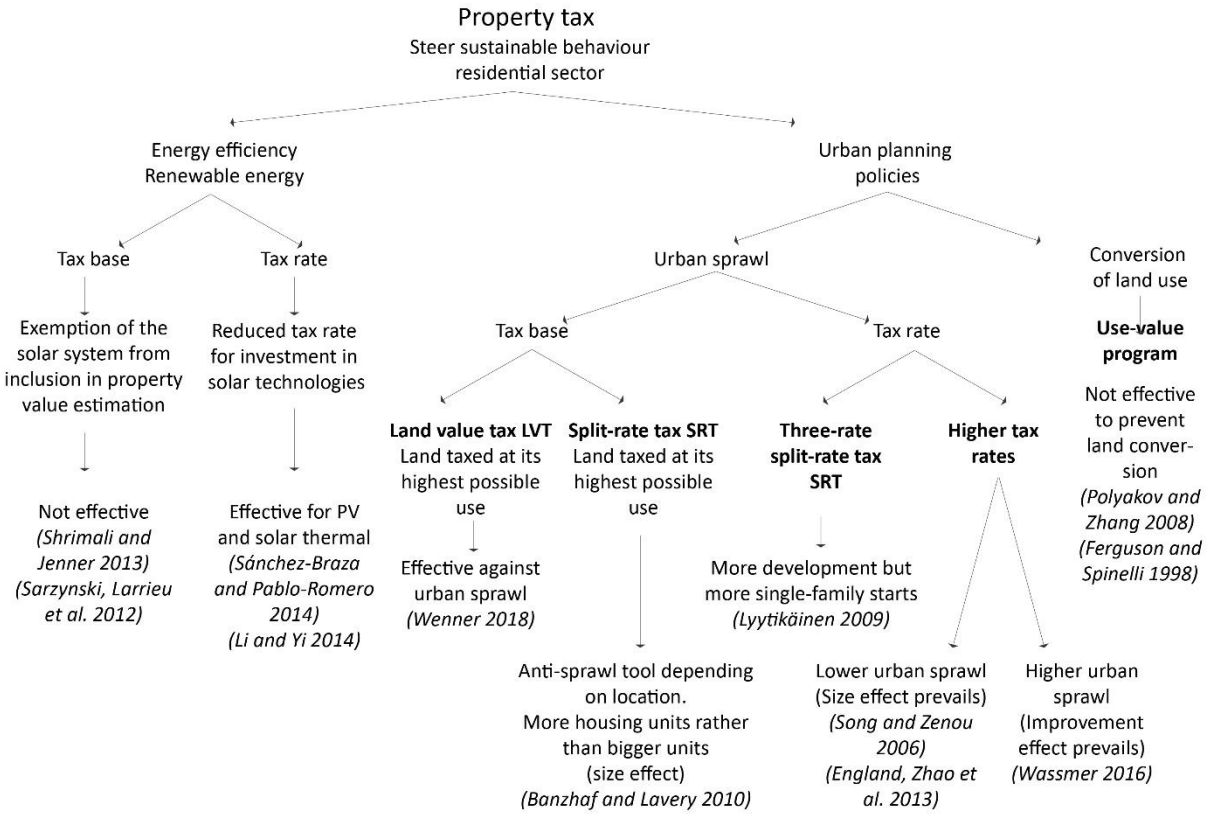

Figure 2 Property tax regimes as levers for policy goals.

Elaborated based on the evidence from literature review.

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APPENDIX

List of abbreviations:

PT – property tax

RE – renewable energy

PV – photovoltaic

TBC – Technical Building Code

CEE Countries – Central and Eastern European

Var – variable

OLS regressions – Ordinary Least Square regressions

Appendix 1 Studies property tax and renewable energy deployment

Study	**Case study location/** **Renewable energy technology**	**Type of study**	**Variables**	**Type of property tax incentive** (Reduction, exemption, rebate)	**Bases of the reduction** (Cost of green component, level of green certification, etc.)	**Alternative policy instruments**	**Results**
(Sánchez-Braza and Pablo-Romero 2014)	Spain, Andalusia Solar thermal energy	Propensity score matching technique	Treatment – municipalities from Andalusia that adopted the real estate bonus, control condition – municipalities that did not; Dependent var - nr of new m^2 of solar systems installed Control var - population, rural, liberal voters, etc.	Reduction of up to 50% of the real estate tax for a period of 1 to 3 years, excluding new construction (regulations TBC)	The tax is calculated by reference of cadastral value (official value of the property)	Tax bonuses on business tax and construction tax from local Gov.; TBC required new construction or renovation projects (30 and 70% of domestic hot water demand)	A tax bonus on real estate tax has a significant positive effect on promoting solar thermal installations on buildings. Tax bonus on real estate tax was an effective promotion measure: Increase in m2 installed with respect to the treated group (municipalities that adopted the measure) is from 41% to 45%. Control group (municipalities who did not) would have had an increase of 71% to 98% if they had implemented the measure. Good results of the policy measure may be associated with the high visibility of the tax. For individuals the tax bonus might imply a significant savings and allows to consider the installation to be profitable.
(Shrimali and Jenner 2013)	US 16 states; PV installations for residential and commercial sectors	Multi-variable regression analysis - impact of 12 state-level policies on cost and deployment of PV;	Dependent var –cost and capacity per year; explanatory var – 12 state-level policies; control var – 5 economic and political var; fixed-effects and vector year var.	Exemptions of the solar system value from inclusion from into the property value	-	Financial incentives – cash, sales tax; command-and-control policies, support policies;	Property tax incentives potentially foster the deployment of commercial systems. In the residential sector – the property tax is significant for cost reduction, but not for deployment. Property tax incentives reduce cost. These financial support policies may be making PV more competitive in the market place.
(Sarzynski, Larrieu et al. 2012)	US Grid-tied PV installations	Time-series cross-sectional (TSCS) fixed effects model: impact of state-level financial incentives on market deployment	Dependent var: annual amount of grid-tied photovoltaic capacity installed in a state in KW; explanatory var: 4 state financial incentives; control var: other state policies, electricity prices, per capita GDP, population; time fixed-effects and vector of time var.	Preventing an increase in property value assessments after installation.	-	Cash incentive (rebates or grants) is effective, while income and sales tax incentives did not have any impact. RPS effective.	States offering cash incentives (rebates or grants) had significantly stronger market deployment than states not offering, while states offering tax incentives (income, property and sales) did not have stronger deployment. The differential effects of the cash vs. tax incentives may be related to the effective size and the ease with which it can be claimed. Avoiding a penalty may be less of an incentive compared to income or cash incentives.

		of grid-tied PV:					
(Matisoff and Johnson 2017)	US Residential PV installations	Regressions - compare effectiveness of 400 state and utility incentives to promote PV using standardised net present value (dollar per W) of each incentive.	Dependent var state-level data on residential PV installations. Explanatory var: local and state incentives: direct cash incentives, PT incentives, sales tax incentives, tax credits, renewable portfolio standards. Other policies: net metering and subsidised financing	Only $/W or $/kWh type of PT incentive considered	-	Over 400 state and utility incentives	Only direct cash incentives, when coupled with financing initiatives and net metering appear to be effective. Each additional dollar of incentives has led to on average, an additional 500W of additional installed capacity per 1000 residential electric consumers. PT reduction, among other tax reduction do not appear to alter residential PV installation behaviour. Incentive salience may drive variation in effectiveness. Many homeowners pay PT in a bundle with insurance and mortgage costs, PT benefits may not be salient. Magnitude of PT incentive: of the 0.91 dollar average total incentive, 0.03 dollar was a PT incentive.
(Li and Yi 2014)	US PV installations	Ordinary Least Square (OLS) regression model	Dependent var Y solar PV capacity installed; Explanatory var state level policies and local solar policies; control var solar radiation, solar systems on gov-owned properties, education, population, fiscal health.	State level incentive - Property tax incentive; local level incentives - property tax abatements, property tax credits;	-	State level policies: renewable portfolio standard; Solar carve-out, net metering;	Local level financial incentives (including prop tax reductions) are significant. State level incentives, net metering, educational programs, expedited permitting, local solar goals are not significant.

Appendix 2 Studies property tax and sustainable energy use

Study	**Case study country/ region / city**	**Urban sprawl / land use**	**Type of study**	**Variables**	**Type of property tax incentive** (Reduction, exemption, rebate)	**Property tax base**	**Alternative policy instruments**	**Results**
(England, Zhao et al. 2013)	US, 41 towns and cities in New Hampshire	Residential development - lot size, living space and building height	Regressions. Hypothesis: Increase in PT rates will reduce lot size, living space and building height of newly constructed single-family houses	Data 36000 houses built in New Hampshire during 1985-2006. Dependent var: lot size, living area and building height of newly constructed single-family homes. Explanatory var: PT rates, public expenditure on local services, zoning regulations, location characteristics, local economic conditions. Control var: provision of water and sewerage services, year var, county var.	-	-	Zoning regulations	Higher PT rates are associated with both smaller lots and smaller houses (fewer stories and less living space). Local PT discourages capital investment. Design of new residential properties is less sensitive to property taxation in communities closer to Boston. Elasticity of lot size, living area and buildings height with respect to the PT rate – a 10% increase in PT rate would be associated with a 1.8% decline in living space and a 4% decrease in lot size and would increase the floor-area ration of the average new home by 2.2%. PT affects allocation of residential capital across municipalities.
(Song and Zenou 2006)	US	Urban sprawl	1) Theoretical econ model – urban land-use equilibrium in a linear and closed city. 2) National sample of effective tax rates. GIS methods for 448 urbanised areas. 3) 2SLS regression	1) Hypothesis: An increase in the PT decreases urban sprawl. Dependent var size of the urbanised area in 2000. Control var population, income, agricultural land rent, commuting cost in 1997. 3) Regression analysis – effect of the PT on the size of the urban area.	-	-	-	An increase in the property tax reduces the spatial extent of urbanised areas – the coefficient is negative and statistically significant. Magnitude of the coefficients, elasticities of urban size with respect to significant var – a 1% increase in population leads to a 1.52% increase in urban spatial extent and 1% increase in the effective property tax rate reduces the urban spatial extent by 0.4%.
(Wassmer 2016)	US 370 urbanised areas (UA)	Effect of PT rates on urban sprawl. Influence of the effective rate of	Regression analysis H1 As PT rate rises, a negative influence on capital intensity could occur (greater sprawl) through less multi-	2) Dependent var - natural log of square miles of a land area of UA. Explanatory var effective tax rate and population of UA. Control var: resident housing preference, development constraints, commuting costs, urban	Effective tax rate (as opposed to statutory rates). Proxies - PT rate for a median value single-family home, single-family home with 150000$ market value and	-	-	Higher rate of effective PT increases the amount of land used for a given population (greater urban sprawl). Differences in rate of effective PT distort the amount of improvements undertaken on raw land and influence the square mile size of UA. A one-standard deviation increase in an effective tax rate results in about a 2 to 4% increase in a UA's land consumption for a given level of population.

		residential PT on urbanised area land area after holding population constant.	story structures built -*Improvement effect.* H2 Positive effect on capital intensity could occur (less urban sprawl) through switching to smaller houses on smaller lots - *Dwelling Size Effect.*	fringe land cost, flight from blight, economic factors, local fiscal structure, preferential PT treatment, dummy var accounting for fixed effects that do not vary across a UA.	600000$ market value rental apartment).			A 1% rise in population yielded nearly a unitary elastic response in land area. Improvement Effect (encourage more one-story units, less population density and greater sprawl) is stronger than countervailing Dwelling Size Effect (each household desires a smaller square-foot total floor space resulting in in greater population density and less sprawl). These results support the desirability of considering a reduction in reliance on traditional PT as applied to both structural value in a parcel, and possibly replacing it with a PT more heavily assessed on only a parcel's value of its land.
(Lutz 2015)	US Municipalities of New Hampshire state	Relationship between PT and new home construction	Regression analysis. RQ Is the location of residential capital investment influenced by PT burdens?	Dependent var residential investment: nr of single-family home building permits divided by the stock of existing single-family homes; house prices measured as the mean sales value of existing homes in a municipality. Explanatory var: fiscal shock measure is a function of time-invariant arguments (per-pupil property wealth), municipal tax burden in the year prior to the reform. Control var: municipal fixed-effects var, year fixed-effects to account for state-wide difference in building activity.	Unusual school finance reform in the state. The state issued large scale grants to municipalities, which were used to fund PT reduction and resulted in a tax shock.	Besides the tax shock, developed land structures are assessed at their market value, while undeveloped land (e.g. forested land) is assessed at only a small fraction of its market.	-	Communities with a reduced tax burden experience a substantial increase in residential construction. Supply of new homes is quite sensitive to PT liabilities: a community receiving the mean grant of 15% of pre-reform local PT revenue experiences 11-22% increase in residential investment. Within the suburban ring of Boston the shock of the tax reform clears through a price adjustment, i.e. by capitalising into property values due to differing housing supply elasticities in the suburban ring relative to the rest of the state. Communities which experience a decrease in PT burdens and witness a surge in the building activity as a result increase the stringency of their land use regulation that will likely slow the growth in the supply.
(Ehrlich, Hilber et al. 2018)	36 European countries	Urban sprawl	OLS regressions H More decentralised countries are characterised by more dispersed residential development.	Dependent var as proxy for urban sprawl - data from high resolution satellite imagery to compute index of the special dispersion of residential settlements. Explanatory var - institutional setup (decentralisation) proxied as dummy var subnational autonomy, dummy var federal constitution, nr tiers (nr of levels of gov) and regional autonomy index that summarises different dimensions of gov decentralisation. Control var logarithm of GDP per-capita, dummy var for Central and	-	-	Decentralisation (institutional setup) determines planning policies and fiscal incentives. Planning policies (land use policies) such as green belts, preservation policies for urban containment.	Institutional setting (decentralisation) is significantly positively correlated with urban sprawl. Decentralised countries have a 25-30% higher sprawl index than centralised ones. Degree of urban sprawl increases significantly with the number of municipalities. Centralised systems often lack sufficient fiscal incentives for local gov to allow residential development, making housing supply inelastic and causing housing shortages and price increases. CEE Countries display a higher degree of urban sprawl. Urban sprawl is significantly negatively correlated with the growth of real estate prices. Trade-off between urban containment and house affordability: countries that allow residential development outside urban areas have low house price growth. Countries with strict containment policies (e.g. UK) with extensive green belts are today confronted with serious housing affordability.

				Eastern European Countries (CEE).				
(Oates and Schwab 1997)	Pittsburgh city	Urban development (building activity)	Regression analysis, sample of 15 cities, including Pittsburgh. Effect of the tax reform - increased rate on land (5 times the rate on structures) on economic activity.	Dependent var average annual value of building permits. Model 1 – regressed the log of data on a constant and dummy var (tax regime-shift var) of 1 for 1980 and after (when tax reform) and a value of 0 of earlier years. Model 2 – a constant, dummy var and a time trend. Control var – economic "climate" (office demand-downtown office vacancy rates)	Property tax abatements for new construction – city did not tax the value from new construction for the first 3 years – magnitude something like a 1.5% subsidy (reduction in price) to new construction.	Land is taxed at more than 5 times the rate on structures.	-	Following the change in tax regime (land 5 times the rate on structures) Pittsburgh experienced a striking building boom, primarily in commercial building activity (residential only a modest increase). Mainly due to excess demand for office space due to transformation of economy from manufacturing to service-oriented. Yet, other cities with the same rates of office vacancy did not experience the same boom. Even after allowing the significant effect of office vacancy rates, the dummy var for the tax regime change remains large and statistically significant. Yet, since the fiscal reform took place in a setting of strong demand for office space, we cannot conclude that the tax reform in itself is capable of generating major urban renewal efforts. The reliance on increased land taxation played an important role in the increase in the building activity by enabling the city to avoid rate increases in other taxes that could have impeded development. Shift of tax regimes is part of larger program, Renaissance II and it is impossible to disentangle fully the effects.
(Banzhaf and Lavery 2010)	Pennsylvania	Effect of split-rate tax (SRT) on urban sprawl (improvement effect split into density and the dwelling size effects)	Difference-in-difference-in-difference model (OLS regression model); non-parametric propensity score matching model	Dependent var: capital/land ratio (improvement effect) proxied as nr of rooms per square mile, proxy for density effect is the nr of housing units in each tract, proxy for dwelling size effect is the average number of rooms per housing unit. Outcomes over a decade. To control for effects that are distributed in space a vector includes interactions of the between decade effects and communities' location in terms of degree latitude and longitude.	-	SRT taxes both land and improvement, but does so at differing rates, with more weight put on land.	-	Split-rate tax (SRT) leads to "smarter" growth patterns, it raises the capital/land ratio (total number of rooms per square mile) by 5-6% points per decade relative to control areas, the effect is more housing units rather than bigger units (size effect appears to be modest, increased capital implies greater density for the city). Results show that SRT did not encourage the construction of detached houses, but appears to increase the construction of high-density structures with 5 and more dwelling units. SRT tax is potentially an anti-sprawl tool, it increases the number of housing units and these units follow denser pattern of development. SRT could be useful to be adopted for a jurisdiction on the fringe of the metro area. If SRT is applied in exurbs or rural areas, any resulting increase in density would mean an increase in urban sprawl. SRT is a toolkit for urban planners that should be used in the right time and place.
(Lyytikäinen 2009)	Finland	Effect of three-rate tax PT on residential development (housing construction)	Hypotheses of the empirical model (regressions): Pre-development tax out to lead to faster development. Wider difference between pre and post-development	Empirical model housing starts are regressed on the difference between the pre- and post-development land taxes. Dependent var housing starts (segregated by single-family housing and all housing starts) and volume (in cubic meters)	Tax reform municipalities allowed to tax undeveloped land zoned for housing at a higher PT rate than developed land – the three-rate tax property tax (3 different tax rates on	With two-rate system post-development taxable value is defined as "what the site would be worth if there were no structures on it?" tax on land is	-	Taxing undeveloped land at a higher rate than developed land has a positive effect on single-family starts. Landowners respond to the tax incentives, municipalities that adopted the three-rate PT system saw an increase in single-family housing starts of 12%. 1% point increase in the pre-development tax rate is associated with an increase in single-family housing starts of 5.5%. The estimates are slightly lower for all housing types than for single-family housing starts (singe family starts are more responsive to tax incentives than larger units) because singe family starts

			land tax should speed development. Side effect – density might be affected. Two-rate system land tax is neutral.	per start (development density). Control var housing prices, housing stock per capita, province level year effects and common quarter dummies.	land before development, on land after development and on buildings). Other municipalities kept the previous two-rate system – uniform land tax and a building tax.	neutral if the taxable value of land does not depend on the landowner's actions. With three-rate – preferential tax treatment for developed land, not for undeveloped		are more likely to be market driven and more affected by land taxes than multi-unit housing starts. The density of development is not affected. Price elasticity of housing starts is 1.13 for single-family starts and 9.58 for all starts. Two-system general property tax is a neutral land tax. Limitation: results may partly reflect the market conditions.
(Wenner 2018)	Tallinn and Riga	Effect of the land value tax (LVT) on urban development (residential constructions) in Tallinn in comparison with conventional building-based tax in Riga.	No regression analysis, only descriptive statistics Hypothesis: Expected positive effect of a LVT – an increase in the inner-city population and building density and a reduction in urban sprawl in the suburban area.	Success of LVT with regard to density. Var: population density, residential building density and residential buildings construction as a proxy for compact city. 3 scales: 4) Macro level – large-scale suburbanisation processes. 5) Meso level – differentiate between core city and inner metropolitan area. 6) Micro level – suburbanisation processes within city boundaries.	Land value tax (LVT). Rate of 1% and since 2012 exemptions for owner-occupiers.	Tax levied only on the value of the every plot of land without taking into account the value of improvements built on it. Market value reflects the theoretically possible, not the current actual use.	-	Results seem to suggest an increased capital-land-ratio and slightly increasing population density in Tallinn as opposed to Riga. Yet, both regions show considerable suburbanisation and sprawl, challenging the effectiveness of the LVT implementation in Tallinn. Data show that capital-land-ratio in Tallinn raised stronger than in Riga. However, the relative growth of floor space to area of municipality was even stronger in the metro areas of both cities. The reason might be the prospering and growing Tallinn region in general rather than LVT. LVT can incentivise construction in central areas to prevent additional sprawl. However, large brownfields in prime locations in Tallinn point to the fact that buildings are not necessarily the most profitable use for land, e.g. as fee-based parking sites. LVT rate (1%) in Estonia is not high enough to exert enough pressure on landowners for more land intensification in central locations, its steering power is too weak.
(Polyakov and Zhang 2008)	US, Louisiana	PT and land-use conversion Aim: Analyse effect of PT and current use valuation program in Louisiana on land-use changes.	Random parameters logit (RPL) model. 2000 repetitions with Halton sequences. Land uses: agricultural, forestry, developed, and Conservation Reserve Program (CRP).	H Higher PT to a particular land use decreases the probability of land being retained in or converted to this land use. Dependent var – the choice of land use and the end of five-year period as a function of var at the beginning of the period. Explanatory var PT per acre for different land use. Control var: plot-level land quality, per acre agricultural returs, forestry returns, returns of developed lands,	Preferential PT treatment of farmland and other rural lands. Agricultural and timber lands are assessed for the tax purpose at 10% of use value. Other lands are assessed at 10% of fair market value. Current use valuation provides substantial tax relief to landowners.	Louisiana's use-value program is pure preferential assessment. It means that eligible lands are taxed on the base of current use value. If a land is converted to ineligible for preferential taxation, it is reassessed on the base of market value.	Conservation Reserve Program	However, land-use transition probabilities are inelastic with respect to PT. According to the simulations, removing the current use valuation system would increase developed land with a magnitude of 0.2%, while it would increase the surface of forest lands with 1.3%.

				effect of population and proximity to populated places.				
(Ferguson and Spinelli 1998)	US, Virginia	Land use – conversion of farm land	Time-series analysis Assess the effectiveness of use-value taxation in slowing conversion of farmland to non-farm use.	It establishes the trend before and after the adoption of use-value taxation and uses time-series analysis to test the differences between predicted and actual loss of farmland. H the census data would show less conversion than could be predicted from the historic data (prior the use-value programs). The year is the predictor var and farm acreage percentage is the dependent var.	Use-value taxation – tax incentives or relief programs used to offset urbanisation pressures.		Rewarding developers for fill-in development on smaller vacant parcels.	The H could not be verified in any of the study locations. No correlations exists between the introduction of use-value taxation and a slower rate of farmland conversion. Not only didn't decrease but even increased twice the censuses exceed the prediction plus error, the conversion of farmland was greater than predicted, not less, in Prince William County. Use-value taxation has had little if any effect on the conversion rate. Lack of effectiveness of the use-value program has had an unintended consequence: neither the localities, not the state have studied or experimented with other means of preserving farmland such as rewarding developers for fill-in development on smaller vacant parcels.