

Evaluating instruments stimulating sustainability transitions: promoting biomass boilers in Germany and the UK

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ABSTRACT

Germany's Market Incentive Program (MAP) and the UK's Domestic Renewable Heat Incentive (RHI) are economic instruments promoting the uptake of small-scale renewable heat, yet to date, a technology-specific evaluation comparing their impact on the uptake of biomass boilers in existing residential dwellings is lacking. The comparison yielded insights into the relative advantages and disadvantages of Germany's upfront subsidies, and the UK's tariff payments for renewable heat generated. A review of academic and grey literature as well as semi-structured expert interviews were used to evaluate the instruments according to a combined theory-based and sustainability transition evaluation framework. The Domestic RHI faced challenges limiting scheme overpayments and responding quickly to issues, due to an inflexible instrument design which required time-consuming parliamentary approval for scheme modifications. Both instruments struggled to balance flexibility and stability, with historic variations in financial support-levels negatively impacting their predictability. The MAP was significantly more stringent regarding emission and efficiency standards than the Domestic RHI, while the amount of financial support provided by the Domestic RHI was more than three times higher than the MAP for a reference 25kW pellet boiler installed in 2019 generating 20,000kWh annually. Nonetheless, uptake under the Domestic RHI was seven to ten times lower than the MAP. A consideration of contextual factors revealed that the UK faces challenges promoting biomass boiler uptake due to its low endogenous biomass supply, immature biomass boiler market, and negative perceptions regarding biomass boilers, illustrating the importance of contextual factors on the success of implemented policies.

Introduction

The European Union (EU) has adopted the 2030 Climate and Energy Framework, which commit it to a 40% reduction in greenhouse gas (GHG) emissions from 1990 levels, with net-zero emissions targeted by 2050 (EC 2014, 2018). The heating and cooling sector is the largest energy consumer in the EU, representing around half of total final energy consumption (EC 2016). With approximately 75% of final energy in this sector currently provided by fossil fuels (EC 2016), it is a major contributor to EU GHG emissions. The largest demand for heating and cooling comes from the residential sector, which uses 45% of heating and cooling in the EU (EC 2016). As most homes today will still be in use in 2050, decarbonization in the residential sector will need to be delivered primarily through retrofits rather than new buildings. The newly issued 2018 Energy Performance of Buildings Directive EPBD (Directive (EU) 2018/844) states that all member states should establish a strategy to transform all existing buildings into nearly-zero energy buildings by 2050 (European Parliament 2018).

However, efforts to decarbonize the existing residential building stock face challenges. Renovation rates are currently too low, the deep renovations necessary to achieve long-term objectives are still disruptive and costly, and costs for renewable heat generation sources remain high (Behr et al. 2016). Additionally, the heat sector has significantly higher heterogeneity than the power sector with regard to technologies, market structures, variety of participants and cost structures, which increases the difficulty of implementing an effective policy (FVEE 2015).

To achieve the desired transformation, the development and diffusion of low-carbon technologies is widely seen as pivotal (Auld et al. 2014; Ockwell and Mallett 2012). Biomass-fueled technologies are one renewable heat source already making a strong contribution to renewable heating in the EU, comprising 17% of all energy used for heating and cooling (Camia et al. 2018). In existing residential buildings, biomass boilers typically combust woody biomass in the form of wood pellets, chips or logs to generate steam or hot water, which can be used for domestic space heating and hot water. Their technological development has progressed such that they can achieve high efficiencies and low emissions (FOREST 2015) and could make a strong contribution to renewable heat objectives. In addition to providing renewable heat, their fuel supply chains have the potential to support rural economies and they can improve energy security by reducing a reliance on imported fuels such as heating oil and gas (García-Maroto, Muñoz-Leiva, and Rey-Pino 2014; Jewell 2011). Consequently, many member states have implemented policies to promote their uptake.

It has been emphasized that understanding an instrument's specific impact on different technologies is necessary to design effective instrument mixes that support the full extent of low-carbon solutions needed to deliver ambitious energy transitions (Rosenow, Kern, and Rogge 2017). To date, however, research exploring the impact of economic policy instruments on biomass boiler uptake in residential buildings is limited. Existing studies consider renewable heat collectively, e.g. Toka et al. (2014), and not biomass boilers specifically. This study thus takes a technology-specific approach to investigate the impact of instruments on the uptake of biomass boilers.

Germany and the UK were selected for evaluation. These countries contributed the highest and third-highest carbon dioxide equivalent (CO₂e) emissions respectively in the EU-28 in 2017 (Eurostat 2019). Germany owns the largest stock of installed pellet boilers in residential applications in Europe (Bioenergy Europe 2018), and has had in place a subsidy scheme supporting renewable heat since 2001 called the Market Incentive Program (Marktanreizprogramm) known as the MAP. The UK has historically had a very limited small-scale biomass boiler market, but in 2011 introduced an innovative renewable heat subsidy policy called the Renewable Heat Incentive (RHI), which was the first economic subsidy for heat to provide a subsidy payment based on the amount of renewable heat generated (Connor et al. 2015). For renewable heat, it is not yet clear under which circumstances the adoption of a tariff subsidy for heat is appropriate. Studies have suggested applying a tariff to heat is more complex and open to risk than applying it to electricity (Connor et al. 2013).

The objective of this study was to gain insights into the effectiveness of policy instruments supporting the uptake of biomass boilers in Germany and UK, and to contribute to an understanding of the relative strengths and weaknesses of upfront subsidies versus ongoing tariff payments for the promotion of renewable heat. The main research question investigated was the following: ***How do the key economic instruments promoting the uptake of small-scale biomass boilers in existing residential dwellings compare between Germany and the UK?*** This paper summarizes the main findings of Morgan (2019) which comprehensively evaluated the policy mix in each nation. Where relevant results have been excluded for brevity, this is noted.

Methods

Evaluation framework

The evaluation approach adopted is represented in Figure 1. The overall dependent variable was the uptake of small-scale biomass boilers in existing residential dwellings.

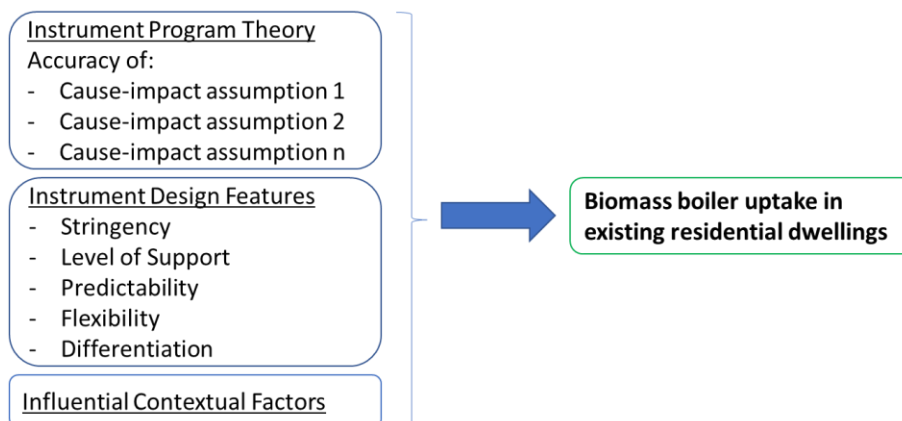


Figure 1. Evaluation approach adopted.

Program theory evaluation is a bottom-up approach which maps out how a policy intends to meet its objective in the form of a sequence of cause-impact relations, and then evaluates the accuracy of these assumed relations (Rossi, Lipsey, and Freeman 2004). An important strength of this approach is that it allows evaluators to not only conclude whether an instrument was successful or not, but also understand why it succeeded or failed, and how it can be improved (Harmelink, Joosen, and Blok 2005). Program theory was used to establish how effective each key economic instrument was in meeting its objective by assessing the degree of achievement of each of the cause-impact relations underlying its intended operating logic.

The achievement of an instrument's objectives, however, does not mean that overall sustainability transition objectives are being met, for instance an instrument may be unambitious. To enable this further level of evaluation, instrument design features were considered. Instrument design features are recognized as being influential for an instrument's innovative effects as well as impacting instrument effectiveness and efficiency (del Río González 2009; Rogge and Reichardt 2016). **Descriptive design features** summarize the content of a policy instrument (del Río 2012), for instance legal form and duration of operation, while **abstract design features** denote normative desirable instrument characteristics. Abstract design features have been established over time in the literature and five abstract design features, suggested as being important in Rogge and Reichardt's (2016) extended framework for the analysis of policy mixes for sustainability transitions, were selected for this study. These comprised the following: (i) **Stringency** - The ambition level of an instrument with respect to its innovative push; the greater the stringency, the greater the incentive to change, (ii) **Level of support** - Magnitude of positive (usually financial) incentives; a "reasonable" subsidy rate should in theory adequately balance incentives and efficiency, (iii) **Predictability** - The degree of certainty associated with an instrument and its future development for impacted stakeholders, (iv) **Flexibility** - The extent to which innovators can freely choose how to comply with an instrument's eligibility requirements and, (v) **Differentiation** - The extent of appropriate differentiation specified by the instrument, e.g. according to plant size or technology-type.

In the final level of analysis, contextual factors influencing biomass boiler uptake, such as fuel prices, were qualitatively evaluated. The effectiveness of each instrument promoting the uptake of biomass boilers is ultimately determined by the attributes of the instrument and influential contextual factors.

Research approach and materials

The steps comprising the approach taken are summarized in Figure 2. The program theory evaluation for each instrument (Step 4) consists of the following: (i) an identification of all implicit and explicit assumptions underlying how the policy is intended to have its desired effect (its ‘program theory’), (ii) a translation of the program theory into concrete (quantifiable) indicators to measure if each cause-impact relation actually took place, and if possible, measure if the change was due to the policy instrument, (iii) development of a flowchart which visually indicates all cause-impact relations, associated indicators, and interacting instruments, and (iv) an evaluation of the extent to which each cause-impact relation took place as intended through a consideration of available empirical data applicable to each indicator.

1. Establish instrument descriptive design features
2. Establish instrument main features and objectives
3. **Evaluation** of instrument program theory
4. **Evaluation** of instrument abstract design features
5. **Evaluation** of influence of contextual factors
6. Synthesis of findings and inferences of determinants of biomass boiler market development

Figure 2. Research approach adopted. All steps treat small-scale biomass boilers as the object of analysis.

The research materials used included a review of academic and grey literature and 12 semi-structured interviews with academic, government and industry experts. The interviews took place between May and September 2019. Eleven interviews were conducted over the phone and one was conducted in person. Interviews took one hour on average. The six experts interviewed from Germany included four from research, one from government, and one from industry. The six experts interviewed from the UK included one from research, two from government, and three from industry. Interviews were conducted to validate the program theory generated for each instrument and support the evaluation of each instrument’s program theory and abstract design features.

Results

Instrument-level evaluation of MAP and Domestic RHI

Instrument descriptive design features

A comparison of the descriptive design features of the MAP in Germany and the Domestic RHI in the UK are indicated in Table 1. The MAP is split into two schemes: upfront subsidies for systems under 100kW, and loans with favorable interest rates for installations greater than 100kW which were not considered in this study.

Table 1. Instrument descriptive design features

Descriptive design feature	MAP (Germany)	Domestic RHI (UK)
Primary purpose and type	Demand pull - Economic instrument (upfront investment subsidy)	Demand pull - Economic instrument (feed-in tariff for 7-years post-installation)
Period active	In place since 1999. No scheduled end date	Launched April 2014. Funding committed until March 2022
Budget	€210.6 million (2017)	£90 million (€102 million ¹) in 2016-2017
Target scope	Existing & new buildings. Solar thermal, heat pumps and biomass renewable heat technologies	Existing buildings. Solar thermal, heat pumps and biomass renewable heat technologies
Jurisdiction	Germany-wide	England, Wales, Scotland
Target group	Homeowners, businesses	Homeowners, self-builders, private and social landlords
Legal form	Policy instrument under the EEWärmeG since 2009. Previously not legally anchored	Instrument under the Energy Act 2008
Implementing agent	Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA)	Ofgem (Department for Businesses, Energy & Industrial Strategy (BEIS) develops the scheme policy and rules)

Sources: Fichtner 2018; NAO 2018.

Instrument main features and objective(s)

An overview of the main features of each instrument including their objective and how they support small-scale biomass boilers is presented in Table 2.

Table 2. Comparison of main features of the MAP and Domestic RHI

Feature	MAP (Germany)	Domestic RHI (UK)
Instrument objective (all technologies)	1,700GWh renewable heat annually (2015-2020) ²	1,400GWh renewable heat by 2020 (ambition level only)
Applicant eligibility	5-100kW. Includes commercial	Up to 45kW (if more than one renewable heating technology, up to 70kW). Commercial not eligible
Cost-effectiveness	Biomass: €16.3/tCO ₂ e (2017)	Biomass: £129/tCO ₂ e (€146/tCO ₂ e) (2018)
Percentage of all accredited systems that are biomass boilers	24% (2002-2017) 38% (2017)	18% (2014-2018) 6% (2018)
Quantity of supported biomass boilers	440,000 (2002-2017) 27,500 average per year	12,468 (2014-2018) 2,802 average per year
Supported biomass boiler types	Wood chip, wood pellet, wood log (gasification only)	Wood chip, wood pellet, wood log
Average size supported	Wood log: 27 kW, Wood chip: 46 kW, Pellet: 21 kW	All: 26.1kW

Sources: BEIS 2019; Fichtner 2011, 2016, 2018; Frontier Economics 2017; NAO 2018.

¹ All values in UK pounds are expressed in 2019 Euros (1GBP: 1.134EUR)

² Includes uptake of systems above 100kW eligible for loans

Program theory evaluation

The performance of each instrument against the indicators developed in the program theory evaluation is presented below. The flowcharts developed indicating all cause-impact relations and associated indicators can be found in Morgan (2019).

Absence of funding shortages:

In 2006 applications were rejected under the MAP due a higher than expected uptake which exhausted the instrument's budget (INER 2013). The MAP also periodically stopped on May 3rd 2010 after the German federal government approved a budget freeze, in large part due to the fallout from the global financial crisis (Baulinks 2010b). After significant criticism from affected stakeholders the freeze was abolished on July 12th 2010 (Baulinks 2010a) with an amount of €115 million made available for the remainder of the year (Baulinks 2010c). Since the 2010 funding freeze, no further funding-shortages have been observed under the scheme. To date, the UK's domestic RHI has remained within budget (NAO 2018). The main budget control mechanism is the use of depressions which automatically reduce the tariff payable if the uptake of a certain technology is higher than anticipated. So far, this mechanism has only been applied to biomass systems.

Consumer and manufacturer awareness of the program:

In Germany, no data on this indicator was found. In the UK, the BEIS stated with respect to the Domestic RHI that there was a "current lack of public knowledge and awareness" (NAO 2018, 21). Between 2015 and 2017 only 12% of homes (18% off the gas grid) were aware of the RHI³ (BEIS 2017a; DECC 2015).

Market response to the program:

Innovation: The MAP defines high efficiency and emissions standards for particulates, carbon monoxide (CO) and nitrous oxides (NO_x) which must be met for units to receive funding, and the market has duly responded by developing systems which meet these requirements. Since 2015, higher funding has existed for biomass boilers with condensation technology, which has had a positive innovation effect by substantially increasing the number of manufacturers offering integrated condensation units (Fichtner 2018). Additional subsidies are also provided for units that incorporate secondary particulate control measures. The number of systems obtaining MAP support for this measure rose from 112 in 2015 to 2,549 in 2017, demonstrating that the MAP has also had a positive impact on innovation in this area (Fichtner 2018).

Decrease in technology capital cost: In Germany there was no evidence of a price reduction in the capital cost of biomass boilers since 2011 (Fichtner 2018), while in the UK, there have been no significant cost decreases since the commencement of the Domestic RHI in 2014 (NAO 2018). It was posited by one interviewee and in Fichtner (2018) that in Germany, manufacturing productivity gains have been offset by increasing safety and environmental requirements.

Scheme non-compliant overpayments as share of total payments:

No data on this indicator was found in Germany. In the UK, the heat consumption rate, upon which the tariff payments are based, is usually obtained from the estimated energy consumption of the dwelling according to its Energy Performance Certificate (EPC) (Ofgem 2018)⁴. These estimates, however, are often not accurate. Overpayments for 2016-2017 were estimated at 2.5-4.5% of total payments (NAO 2018). The tolerable level of overpayment was defined by BEIS at 3% (NAO 2018). One interviewee reported that there was anecdotal evidence of fraud where companies would issue EPCs with overinflated energy demand figures, leading to higher tariff payments being received by the applicant.

³ Specific question: Q7_13 'Have you heard of the Domestic Renewable Heat Incentive?'

⁴ In some cases, meters are prescribed to record the actual energy consumption

Evaluation of abstract design features

Stringency:

The MAP has significantly more stringent eligibility criteria than the Domestic RHI regarding particulate, carbon monoxide and NOx emission limits, as well as stipulating a higher minimum efficiency. A summary of the eligibility requirements for each scheme is shown in Table 3. In the UK, wood pellet condensing boilers must meet higher efficiency standards than non-condensing boilers (MCS 2016). The Domestic RHI is more stringent than the MAP in one respect, stipulating that for an installation to be eligible, loft and cavity insulation must be installed if it is recommended on the dwelling's EPC.

Table 3. Emission and efficiency eligibility requirements for biomass boilers to receive support under the MAP and Domestic RHI. UK limits in g/GJ are converted to mg/m³. Noted (*) when stricter than statutory limits

	Particulates upper limit	CO upper limit	NOx upper limit	Minimum efficiency (LHV) ⁵	Minimum efficiency (LHV) – condensing boiler
MAP	20mg/m ³	200mg/m ³ (*)	500mg/m ³	89%	89%
Domestic RHI ⁶	130mg/m ³ (*)	1,000mg/m ³	640mg/m ³ (*)	75%	94% (condensing mode) 87% (non-condensing mode)

Sources: BAFA 2019; MCS 2016; Ofgem 2019a

A lack of stringency was identified as an issue for biomass boilers installed under the Domestic RHI by several interviewees. Customers installing biomass systems in the UK were the least satisfied amongst the eligible Domestic RHI technologies (Frontier Economics 2017). This lack of stringency was cited by several interviewees as contributing to the general negative perception of biomass boilers and the biomass industry in the UK.

Level of support:

The Domestic RHI offers significantly more subsidy support per installation than the MAP. In mid-2019, when the tariff rate payable was 6.88p/kWh, a 25kW pellet boiler generating 20,000kWh annually would receive more than three times as much support under the Domestic RHI compared to the MAP (NPV⁷ of £9,084 (€10,303) vs €3,000). As expected, this higher level of support translates into a lower cost-effectiveness for the Domestic RHI (Fichtner 2018; NAO 2018). Subsidy support levels for both schemes have changed over time. Under the MAP, subsidy levels for a pellet boiler up to 37.5kW have more than doubled since 2007, adjusted for inflation, although this does not seem to have had an impact on biomass boiler uptake, as indicated in Figure 3 (left).

In contrast, tariff levels for biomass boilers under the Domestic RHI have significantly fallen since the commencement of the scheme, as indicated in Figure 3 (right). The tariffs for all technologies supported by the Domestic RHI were initially set based on an estimated typical rate of return of 7.5% compared to an equivalent oil boiler (DECC 2013). When the scheme commenced, the high initial uptake of biomass boilers triggered automatic depressions. Between January 2015 and January 2017 the tariffs payable for biomass systems dropped steadily from 12.2p/kWh to 4.21p/kWh, and uptake correspondently dropped off (Ofgem 2019b). At the beginning of 2018 a one-off increase to the tariff rate was implemented, however, this had little impact on

⁵ LHV (lower heating value) is used for biomass boiler efficiencies, where the energy used to generate steam is not considered in the efficiency calculation

⁶ Emissions need to be below 30grams per GJ net heat input (net calorific value) for particulates, and below 150grams per GJ net heat input for NOx as per Ofgem (2019a). These limits were introduced in September 2013 according to NAO (2018), and thus less stringent national legislation limits applied before this date

⁷ Discount rate of 2% assumed for net present value calculation

biomass system uptake. Industry groups claimed that the reduction of biomass boiler tariffs was too aggressive (Brooks 2016), a view shared by most interviewees.



Figure 3. Left: Subsidy amount payable for a 25kW pellet boiler and number of biomass boilers supported over time under the MAP, adjusted for inflation. Sources: Fichtner 2011, 2016, 2018; INER 2013. Right: Tariff rates payable for biomass systems and accredited systems per quarter under the Domestic RHI. Sources: BEIS 2019; Ofgem 2019b.

Predictability:

The 2010 budget freeze for the MAP, even though it was only for a few months, was claimed by stakeholders to severely impact the market and drive a decrease in faith in government reliability (Baulinks 2010c). One interviewee also reported that many installers were not made aware of the program’s later reinstatement. Applications under the MAP in 2010 were 60% less than in 2009 (Fichtner 2011). Additionally, the funding levels and eligibility requirements have changed regularly over the history of the MAP. In the period 2001-2012, there were 17 changes to the funding amounts or eligible technologies (INER 2013). These frequent changes, according to one interviewee, have been the subject of criticism, and although some flexibility should exist to cater for a dynamic market, on balance the MAP had changed too much. Since 2012, however, there has been only one new directive, with minor amendments, and thus the predictability of the instrument has improved.

In the UK, the delay in the implementation of the program, which was twice postponed, and the operation of the depression mechanism were found to impact predictability. An additional concern voiced by three interviewees was the lack of visibility regarding what will follow the Domestic RHI, as it was due to conclude in March 2021. Recently, it has been announced that the scheme will be extended to March 2022 (HM Treasury 2020). For installers, the most frequently cited negative impact of the RHI was uncertainty due to the nature of the tariff mechanism (Frontier Economics 2017), as there was always the risk that the tariff could change during the engagement of a customer.

Flexibility:

Some technologies, such as the PuroWIN gasification system, are able to deliver very low biomass boiler emissions without a secondary separation technology, but are not eligible for higher levels of funding offered by the MAP for innovative systems (Fichtner 2018). It was argued by an interviewee that the definition of innovative systems should be expanded to include units such as the PuroWIN gasification system.

In the UK, the inability for the government to respond quickly to address issues, which often necessitated parliamentary approval, was pointed out by two interviewees as being a shortcoming of the scheme.

Differentiation:

Under the MAP, higher subsidies are offered for innovative systems incorporating condensation technology, with the aim of promoting innovation and improved system efficiencies. However, as the higher support is linked to the presence of condensation technology, rather than system efficiency, some new models have focused on meeting the eligibility requirement without targeting an optimal design (Fichtner 2018).

In the UK, a lack of differentiation in subsidy support for high-efficiency and low-emission biomass systems was identified by two interviewees as a shortcoming of the Domestic RHI, as opportunities to promote market development and innovation were lost.

Contextual factors

Germany has several contextual factors more favorable for the promotion of biomass boilers in comparison to the UK. Germany is the largest producer of biomass pellets in Europe (AEBIOM 2017), which increases the likelihood that the government will be more amenable to promoting domestic uptake to support energy security. In contrast, the UK is the largest importer of pellets in the EU, although the majority of these are used for biomass-fueled power plants (AEBIOM 2017). While prices for wood pellets were not found to be noticeably different between Germany and the UK (AEBIOM 2017; MSE Forums 2014), Germany has a comparatively low price-variability compared to other EU nations due to its large domestic biomass pellet market. Higher price volatility in the UK was evidenced by the comments of one interviewee who stated that there have been price spikes over colder winter periods due to a shortage of biomass fuel supply. Germany also has a mature biomass boiler industry, sporting the largest pellet biomass boiler stock in Europe, with over 250,000 residential pellet boilers (<50kW) installed as of in 2017 (Bioenergy Europe 2018). In contrast, the UK had a total of just over 10,000 residential pellet boilers (<50kW) installed in 2017 (Bioenergy Europe 2018). Surveys undertaken in an evaluation of the MAP and statistics from the Domestic RHI suggest that biomass boilers are cheaper in Germany than the UK (BEIS 2019; Fichtner 2018). The UK's robust domestic natural gas boiler market has also impaired efforts to promote biomass boilers and renewable heat more generally (Chaudry et al. 2015; Connor et al. 2013). An extensive natural gas network connects 87% of households in the UK (BEIS 2018a), and low natural gas costs, supported by the exploitation of its own fields, has driven down gas boiler operating costs (Connor et al. 2015).

Biomass boilers are most suited to replacing oil boilers, due to their relatively similar space requirements and the absence of a gas connection. In Germany there are approximately 5.5million oil heating units (ZIV 2018), whereas in England (which makes up over 80% of the UK's population) there are approximately 850,000 (BEIS 2017b). Thus, Germany's existing stock of heating systems is better suited to biomass boiler uptake. The price for heating oil, while consistent between both nations, has historically been highly volatile. This strongly impacts the competitiveness of oil and biomass boilers through its impact on operating costs (Fichtner 2018; Toka et al. 2014). A recurring theme from the interviews with UK experts was the view that the government did not plan for biomass boilers to substantially contribute to renewable heat in the future.

Interpreting biomass boiler uptake

Based on the results of the instrument evaluations and a consideration of contextual factors, the main determinants of biomass boiler uptake in each nation were inferred. Figure 4 indicates the number of biomass boiler installations between 2002 and 2019 in Germany, with an indication of the main adjustments to the MAP

and relevant contextual factors, while Figure 5 does the same for the Domestic RHI in the UK between 2006 and 2019.

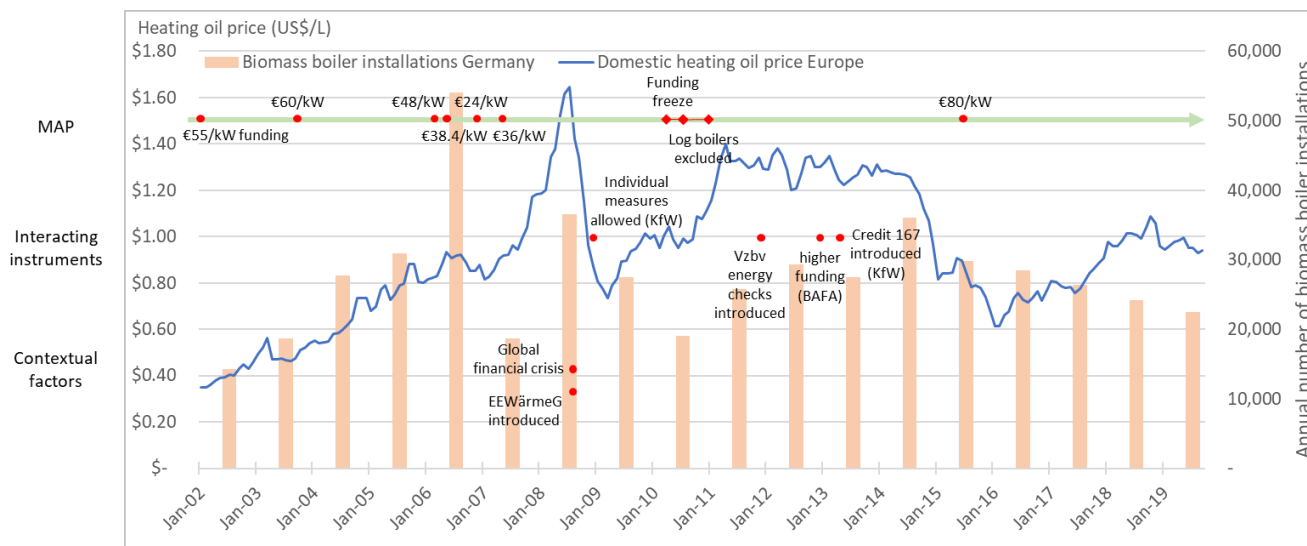


Figure 4. Development of the MAP and biomass boiler installations⁸ in Germany between 2002 and 2019 including relevant contextual factors. MAP funding rates refer to the subsidy received per kW installed power. See Morgan (2019) for details on interacting instruments. Sources: BDH 2009, 2019, 2020; IEA 2019.

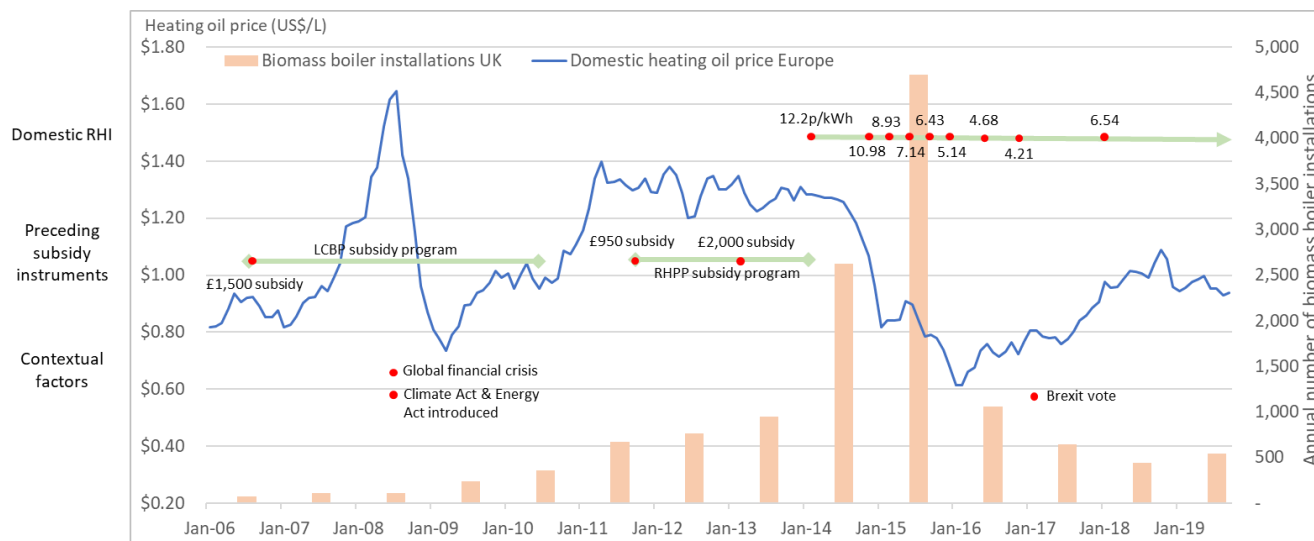


Figure 5. Development of the Domestic RHI and biomass boiler installations⁹ in the UK between 2006 and 2019 including relevant contextual factors. Domestic RHI funding rates indicated refer to the subsidy received per kWh heat generated. Sources: BEIS 2019; DECC 2011, 2014; IEA 2019.

⁸ Germany statistics include biomass boilers of all sizes across households and industry. However, most of these installations will be for households under 100kW as households overall use 2.5 times more heat than industry, as per UBA (2019), and install smaller systems on average.

⁹ No institution in the UK tracks statistics on biomass boiler installations, however since 2006, the number of systems receiving government financial support have been recorded.

In Germany it appears that the MAP and heating oil prices had the most significant influence on the uptake of biomass boilers. In 2001-2005, the subsidy rate offered under the MAP did not change substantially and therefore it seems that the doubling of heating oil prices during this period contributed to the increase in biomass boiler installations. Systems supported under the MAP hit a record high in 2006 resulting in the budgeted funds running out. This led to steep cuts in subsidy support which was reduced from €60/kW to €24/kW, and installations accordingly dropped in 2007. After a small increase in the subsidy rate to €36/kW, combined with heating oil prices reaching a record high in 2008, biomass system installations picked up again in 2008. With the fallout from the global financial crisis and a steep drop in heating oil prices, biomass installations subsequently dropped. Additionally, in 2010 the MAP was frozen for several months, leading to market uncertainty and driving biomass boiler sales lower again. Between 2010 and 2014, the price of heating oil increased and biomass boiler installations picked up. During 2014-2016 the decline in biomass boiler installations correlates with decreases in oil and gas prices, with the increase in subsidy rates under the MAP to €80/kW in 2015 unable to compensate. While heating oil prices from 2017 have increased, this has not yet led to an increase in biomass boiler sales.

In the UK, the Domestic RHI and its predecessor the Renewable Heat Premium Payment (RHPP) have been the key driver of biomass boiler uptake over the period considered. With the introduction of the RHPP in 2011, uptake increased. Even though the subsidy payments offered were initially lower than those offered by the previous Low Carbon Building Program (LCBP) (£950 (€1,078) vs £1,500 (€1,701)), applicants were promised that they would be eligible for support under the Domestic RHI when it was introduced (DECC 2011; The National Archives 2013). Increasing oil prices during this period may also have contributed to more installations. Uptake increased further in 2013, which may have been supported by the increase in subsidy rate under the RHPP to £2,000 (€2,268) after 20th May 2013 (DECC 2014). With the introduction of the Domestic RHI in April 2014, deployment of biomass boilers skyrocketed, increasing almost five-fold by 2015 compared to 2013. The subsidy support seems to have been so high that the 50% drop in heating oil prices between 2014 and 2015 had little impact. The steep decline between 2015 and 2016 appears to be almost completely due to the sharp reductions in tariff payments payable for biomass boilers which were particularly steep between 2015 and 2016, dropping more than 50%. Installation levels dropped further in 2017 and 2018, before showing a slight upward trend in 2019, which may have been due to a combination of increasing market certainty indicated by a one-off increase in the tariff to 6.54p/kWh (€0.0742/kWh) in early 2018 and increasing heating oil prices.

Discussion

The technology-specific approach adopted in this study highlights the differentiated impacts of nominally 'technology neutral' instruments. Hanna, Parrish, and Gross (2016) emphasized that the success of incentives depends on having standards in place for manufacturing, installation and maintenance which are strong enough to maintain the industry's reputation. The experience of UK interviewees supports this notion. Here, a lack of adequate standards appeared to drive negative perceptions of biomass boiler technology, ultimately resulting in their proposed ban from gas-connected urban areas by DEFRA (BEIS 2018b). Purkus, Gawel, and Thrän (2017), in their investigation of the trade-off between flexibility and stability in decarbonization policy mixes faced with high uncertainty and complexity, concluded that there is a need for effective mechanisms to limit the cost of errors and implement policy adjustments. Experiences reported with the Domestic RHI lend credence to this conclusion. Due to the burdensome parliamentary approval required to make scheme modifications to the Domestic RHI, policy design errors in the setting of degression thresholds could not be addressed in time to avoid the collapse of the biomass boiler market.

This study intended to elucidate the relative advantages of applying up-front subsidies or ongoing tariff payments to renewable heat. In the UK, upfront cost was a key concern for 62% of Domestic RHI applicants (NAO

2018), suggesting that some households with the intention to install biomass boilers were excluded from the scheme in the UK. The results of the study appear to support the claim that applying a tariff to heat is more complex and open to risk than applying it to electricity as suggested by Connor et al. (2013). Rather than metering energy use, as is the case for electricity generation tariffs, heat generation under the Domestic RHI was in most cases estimated by referring to the dwelling's EPC. This was a key contributor to scheme overpayments which were estimated to be 2.5-4.5% during 2016-2017.

A key challenge in this study was obtaining reliable data on the number of biomass boilers installed in each nation, the dependent variable for this study. In Germany, different data sources conflicted in some years, while in the UK, other than government reporting of subsidized units, no publicly accessible biomass boiler statistics are available. The reliability of conclusions drawn from the evaluation of the Germany and UK policy instruments would be improved if accurate biomass boiler installation statistics were available. Additionally, the policy theory for both instruments was implicit and had to be reconstructed based on disparate literature, with data also not available for all indicators developed in the program theory flow chart. Overall, more data were found for the Domestic RHI indicators than for the MAP. A further shortcoming was the difficulty of delineating the impacts of the instrument and contextual factors on biomass boiler uptake. This is a universal challenge faced in any policy evaluation, termed the 'dependent variable problem in the study of policy change' (Schmidt and Sewerin 2019). This limitation, however, was minimized by the research design adopted, which intended to holistically consider the full spectrum of possible drivers of biomass boiler uptake.

Further research could support efforts to balance instrument predictability and flexibility by investigating the impact that changes in heating oil prices have on the levelized costs of heating oil boilers compared to biomass boilers in different countries. Such research would inform national policy makers on the extent of flexibility that should be incorporated into policy instruments supporting the uptake of biomass boilers.

Conclusions

This study sought to investigate how the key economic instruments promoting the uptake of small-scale biomass boilers in existing residential dwellings compared between Germany and the UK. In Germany, the MAP was successful in promoting a high volume of efficient and low-emission biomass boilers through the up-front subsidy payments offered and stringent eligibility criteria. In the UK, the Domestic RHI was initially very successful in promoting biomass boilers installations in 2014 and 2015 through the high tariff payments offered for renewable heat generated. However, uptake significantly fell in 2016 in response to steep reductions in the tariff-rate payable due to the triggering of successive depressions as a result of higher than anticipated uptake. Negative impacts to the supply chain development and instrument predictability could not be quickly addressed as the instrument required time-consuming parliamentary approval for scheme modifications. The Domestic RHI and the MAP both struggled to balance flexibility and stability which negatively impacted their predictability. While responding to variable fuel prices is necessary to maintain the competitiveness of biomass boilers, subsidy support levels have changed excessively under both schemes in the past. The UK was found to be a challenging context to install biomass boilers. Even though subsidy support under the Domestic RHI was found to be substantially higher than the MAP, uptake under the Domestic RHI was seven to ten times lower during the years both schemes were in place. A mature natural gas market combined with cheap gas costs, as well as a less mature biomass boiler market, seem to have contributed to the difficulties of making biomass boilers competitive in the UK. Additionally, less stringent requirements under the Domestic RHI appear to have contributed to negative perceptions regarding biomass boiler technologies. These contextual factors are likely to have contributed to the different long-term decarbonization strategies adopted by each nation, with the UK targeting a smaller role for small-scale biomass boilers in the future.

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