Energy & Buildings 253 (2021) 111542

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

Low free-riding at the cost of subsidizing the rich. Replicating Swiss energy retrofit subsidy findings in Norway

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A R T I C L E   I N F O

Article history:
Received 5 May 2021
Revised 30 September 2021
Accepted 1 October 2021
Available online 7 October 2021

Keywords:
Building energy policy
Energy retrofitting
Energy-efficient retrofitting
Subsidies
Free-riding
Norway

A B S T R A C T

Understanding free-riding is central to effective household energy retrofit subsidy policymaking. We replicate a Swiss study on free-riding prevalence in household energy retrofitting in Norway Studer and Rieder (2019). Compared to the original studies free-riding prevalence of 50%, we find only 10%, indicating that Norwegian free-riding is low. Similar to the original study, we find that the use of advisory service and having a good perception of the implementer is associated with not free-riding, but argue these findings should not be interpreted entirely causally, as confounding variables can also explain this association. Finally, we find that Norwegian retrofit subsidies are heavily focused on high-income households, which has ethical implications.

Comparing the subsidy systems of the two countries, our findings indicate that raising the energy standard threshold for receiving retrofit subsidies leads to less free-riding, but could stimulate less retrofitting as a whole and focuses distribution of the subsidies on to rich households.

Contents

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https://doi.org/10.1016/j.enbuild.2021.111542
0378-7788/

1. Introduction

In the EU, private household space heating represented 16.5% of final energy consumption in 2018 [16]. Reducing the energy need for private household space heating is therefore of high importance to reducing household energy footprint, reach targets in the Paris climate agreement, and ultimately minimizing the impact of climate change. Several policies are in place to reduce household energy use, and various forms of subsidies are popular in achieving this. Subsidies for private house energy retrofitting is usually one of the bigger subsidies in the private market. However, the cost-efficiency of these subsidies has been criticized for being low, and "free-riding" is a central part of this critique [57,76].

Free-riding refers to the phenomena when conservation programs finance investments that would have taken place even in the absence of the program [29]. For example, a household that already aims to add a significant amount of insulation to their walls because of environmental and comfort reasons, but learns they can also receive subsidies for the implementation, then applies for and receives those subsidies, is free-riding the subsidies. Research generally identifies a free-riding prevalence of around 30–70% in private household energy retrofitting [49,57,76]. However, free-riding percentages as low as 7% [10] and as high as 92% [27]to almost complete [2] free-riding are also reported. The method of operationalizing and measuring free-riding varies, which is most likely one of the main reasons for the varying estimates, together with structural differences in the policies. Methods used include calculation willingness-to-pay [10], revealed preference data [27], comparing post and pre subsidy rates of retrofitting, and simply inquiring about the amount of free-riding in surveys [76]. One might suspect explicitly inquiring participants in surveys should obtain a lower free-riding frequency than other methods. Still, a recent survey in Switzerland found an explicit free-riding prevalence on energy retrofit subsidies of 50% [76], which is completely normal compared to what other methods reveal. This suggests surveying for free-riding could be a valid method of measuring free-riding.

Identifying and combating free-riding on subsidies is central to creating effective public policies [37]. To effectively combat climate change, public money should be spent where it has the most impact [25]. Comparing the share of free-riders between countries can be an important tool to evaluate the effectiveness of a country's policies. While several articles estimate the share of free-riders, we could not identify studies comparing two or more countries using the same methodology for obtaining free-riding prevalence. Comprehensive studies can be identified regarding heating systems [50], but heating systems differ from building envelop measures. Furthermore, we could not identify any study attempting to replicate other studies methodologies for measuring free-rider percentages in other countries. As both the method for obtaining the prevalence and the definition of free-riding will often vary between studies, comparing the results of different studies using different methodologies for estimating free-riding is problematic. For example, regarding Swiss household retrofit free-riding, Rieder [55] finds a free-rider prevalence of about 10% when asking pre-payout, but 30% when asking post-payout. Some years later, when Studer and Rieder [76] find 50% free-riding in the same country, it is difficult to establish how much of the change should be attributed to methodology, cultural changes, or policy changes.

Therefore, replicating subsidy free-riding studies is important. Firstly, it is an important piece of the puzzle in establishing what kind of policies result in low free-riding. Sufficiently scaled experimental research projects on large subsidies, such as buying electric cars or energy retrofitting, are difficult to finance. Subsidizing 50–100 participants' energy retrofitting can quickly require budgets out of reach for all but the most well-funded projects. This means researchers and policymakers must often rely on comparative studies to estimate free-riding prevalence. Different free-rider prevalence in such studies can stem from three sources. Firstly, the policy affects the free-riding rates. It is this free-riding most studies attempts to measure. Second, differences can stem from cultural differences. For example, prosperous countries can have different levels of free-riding even if the policy is identical. Finally, methodological differences can impact the free-rider prevalence. Rieder [55] found both 10% and 30% free-riding with small methodological differences. Other free-riding research states that their free-riding prevalences are not comparable like-for-like with other research [10]. Norway and Switzerland are both small, mountainous, prosperous, European countries that are only partly members of the EU, making them reasonably comparable. If the methods of Swiss free-rider studies are replicated, the methodological impact should also be zero. This would allow for a more direct comparison of free-rider rates where the differences should be based on policies and not other factors. Secondly, replication remains one of the main pillars of science and is extremely important in establishing a cumulative base of knowledge [64]. Nevertheless, replication in the field of social sciences has been, and is too low, which is a problem in the field as a whole [44]. Therefore, producing replicative studies is of great importance to the field of subsidy free-riding, and science as a whole. We aim to replicate research on Swiss free-riding prevalence [76] in Norway. Firstly, however, an overview of both countries' retrofit subsidy policies is given in the next paragraphs to understand the contexts the two studies have been conducted in.

1.1. Subsidy policies

Norwegian and Swiss subsidy policies have several differences and similarities important for subsidy free-riding. Switzerland has a national target to reduce domestic greenhouse gas emissions by 20% from their 1990 levels by 2020 and be climate-neutral by 2050 (Federal [17]. Decarbonization of the heating sector is needed to reach this [19]. This is promoted by subsidy systems, which are divided into national and cantonal programs. The national subsidies focus on the building envelope, while the cantonal subsidies differ significantly between cantons and offer subsidies for local production of renewable energy (e.g., by photovoltaic installations), waste heat utilization, etc. [20]. The annual Swiss energy efficiency refurbishment rate of the total building stock is about 1%, where the large proportion of rental dwellings are believed to be a key barrier [35]. The mean annual Norwegian temperature is 1.0 °C, compared to the Swiss 5.9 °C [87].

The Norwegian system is managed by the national energy efficiency agency Enova SF, which the Ministry of Climate and Environment owns. Subsidies for several implementations are offered, such as installing hydronic heating (which is uncommon in many older Norwegian houses, usually heated by electric resistance heating or air-to-air heat pumps), and local electricity production. The most important subsidies are offered for "holistic building energy upgrade", where 25% of the costs, up to 100 000–150 000 NOK[1], are reimbursed depending on the final energy level. This type of subsidy will be the focus of the present article. The stated overall strategy of the subsidy scheme is to stimulate market change, so that newly established and more climate-friendly solutions are more readily available and will reach a state as soon as possible where they are no longer dependent on subsidies [13]. Norway also has a loaning scheme for upgrading to the same building standard through "Husbanken", but an average of only 14 private persons have utilized

[1] Approx 10.000–15.000 EURO.

the scheme annually in 2008–2019 [34], suggesting issues related to the scheme. Finally, a free advisory service, 'Enova answers', where households can ask questions about energy retrofitting and subsidies. The Norwegian energy retrofit rate is at a standstill compared to 4 years ago, with a yearly energy retrofitting rate of about 3.4% [22], although a small number of households that retrofits often seem to drive up this number [91].

Because Swiss household retrofit subsidies are canton specific, it is difficult to directly compare to the Norwegian system, but trends can be identified from the recommended canton guidelines aimed to harmonize the subsidies [39,40,68]. The most relevant guidelines for this paper are the 2009 guidelines, as they applied in the period up until 2015 where Studer and Rieder [76] collected their data. At that time, Swiss national building envelope funding funded 15% of the investment costs, but in most cantons, additional "indirect subsidies" of about 20–40% may be deducted from the household taxable income [36]. Notably, the new recommended canton guidelines issued in 2015 increased the minimum funding to 20%. Households are not eligible for funding if the total costs exceed 20% of the funding. The guideline argues that this way, subsidies can sufficiently stimulate demand and not be only for well-informed investors who would have undertaken the measures without funding [68], in other words, free-riders. For the national system, a household is eligible for funding if the retrofitted building was built before 2000, reaches a minimum amount of funding, and can document a minimum level of insulation. The canton recommendations specifically state it does not recommend any specific level of funding, so numbers most likely vary strongly between cantons. The upper limit of the subsidies was set to 50% in the same document, suggesting that subsidies could go above 50% in some cases. Importantly, households are eligible for subsidies when performing the retrofitting both individually or in collaboration with a contractor (Personal communication, Sabine Hirsbrunner, Swiss Federal Office of Energy, September 2020), and subsidies are not only tied to the cost of the retrofitting, but also the outcome [39].

Several aspects of both countries' energy retrofit subsidies are important concerning free-riding prevalence. Subsidies in both Norway and Switzerland can most likely be primarily used by high-income households, which increases free-riding (as suggested by [49]. Norwegian housing energy retrofit subsidies are paid post-retrofit, meaning homeowners must first conduct the retrofitting, then apply for the subsidies. Retrofits that are not completed through a contractor, such as conducting the retrofit yourself, are not eligible for subsidies. This implies that the homeowner must have the financial resources, either through capital or loaning capabilities, to first complete the retrofitting before receiving any subsidies. While high-income households are more likely to have these financial resources, the market does not usually finance energy efficiency measures [31], questioning whether low-income households can finance the investment. This could suggest that subsidies are focused on the high-income portion of the population. Because high-income households are likely more susceptible to free-riding, as they have the financial resources anyway, this could increase free-riding. Similar issues are present in Swiss subsidies. Households cannot benefit from tax deductions if they do not have sufficient income, effectively excluding groups that do not pay enough taxes. They are also paid post-retrofit, meaning households must have the financial means to complete the retrofit before receiving subsidies. This again suggests they could be focused on the high-income households, increasing free-riding. Contrary to Norwegian subsidies, however, households are eligible for receiving subsidies if they complete the retrofitting themselves. This should reduce the barrier regarding available financial resources, making more people eligible for subsidies. The possible income difference related to free-riding is not only an economic problem regarding efficient financial resource allocation aimed at accelerating the energy transition, but it is also an ethical problem in detriment of a fair and just energy transition, which has recently received increasing attention [30,45]; (Pellegrini-Masini, Pirni, Maran, & Klöckner, 2020).

Table 1
Threshold characteristics for energy retrofit subsidies in Norway and Switzerland. Note that numbers are simplified for the sake of comparison.

	Norway	Switzerland
Mean annual temperature	1.0 °C	5.9 °C
Renovation rate	3.4%	1%
Piecemeal retrofits subsidized	No	Yes
Mean energy consumption of households	185 kWh/(m^2a)	112 kWh/(m^2a)
Subsidy eligebility threshold	130 kWh/(m^2a)	90 kWh/(m^2a)

A subsidy scheme's threshold for giving financial aid should be related to the prevalence of free-riding in the region. A high threshold for receiving subsidies should result in less free-riding, as you need to do more to receive the subsidies. In Norway, the energy retrofit must reduce heat loss by 30% and reach an energy rating of (120 + (1600/A)) kWh/(m2a) with A representing the floor area in m^2, to be eligible for retrofit subsidies[2] [12]. Households that achieve an energy rating of (80 + (1600/A)) kWh/(m^2a) are eligible for larger subsidies, suggesting highly ambitious energy retrofits are prioritized. With the most prevalent Norwegian single household house size being 160–199 m^2 [72] this sets the threshold for receiving subsidies around 130 kWh/(m^2a). The average Norwegian household consumed 185 kWh/(m^2a) in 2012 [70]. The Swiss subsidy threshold for building envelopes differs between cantons, which makes pinpointing a common threshold difficult. However, recommended guidelines for the cantons exist [39], and a reasonable comparison can again be made between the subsidy systems by looking into these guidelines. As a rule of thumb, the MINERGIE standard is followed, where single and multi-family homes have 90 kWh/(m^2a) as a core requirement [47]. However, this kWh/(m^2a) value is weighted according to the energy source and end-use, so it is not directly comparable to the Norwegian value. For example, solar energy and geothermal heat weight 0, meaning they are omitted. For comparison, the mean Swiss household final energy consumption has been measured to be 112 kWh/(m^2a) [75]. Additionally, subsidies are also offered for partial retrofitting, such as windows [39]. While the level of subsidies differs substantially between cantons and is difficult to objectively compare to the Norwegian model, it can generally be said that the overall threshold for receiving subsidies for energy retrofitting is lower in Switzerland, and the subsidy level is higher. See Table 1 for an overview.

The threshold for receiving subsidies is important for establishing the most efficient use of public money. A high threshold for receiving subsidies most likely results in less kWh saved for every euro invested, as an exponential connection between renovation cost and kWh saved exists, where the cost increases exponentially the more energy-efficient the final renovation standard is [23]. At the same time, a high threshold for receiving subsidies may lower free-riding. Whether or not a high threshold for receiving subsidies affects the amount of free-riding is therefore also central in establishing the ideal retrofit threshold for receiving subsidies to maximize the reduction in household energy footprint for the least amount of public money spent.

[2] This formula allows for a higher kWh/(m^2a) in small households, because they have a higher surface-to-valume ratio than large buildings. To excemplify, a large 500m^2 building need to reach 120 + (1600/500) = 123 kWh/(m^2a) to be eligible for the subsidies, while a smaller 70m^2 building must reach 120 + (1600/70) = 143 kWh/(m^2a).

For these reasons, we decide to replicate Studer and Rieder [76] findings on Swiss free-riding in Norway. Studer and Rieder's [76] research involves three studies. Firstly, the estimation of free-riding prevalence, which they estimated to be 50%. Secondly, identifying factors associated with free-riding such as the use of advice services, where they found perception of the implementer (how much they liked the subsidizing body), and the use of advice services to be statistically significant factors. Thirdly, focus group interviews. As quantitative measures arguably afford to minimize variability in replications, we decided to replicate only the two first studies.

Replicating Studer and Rieder's [76] research in Norway, we aim to investigate (1) potential differences in free-riding prevalence between Norway and Switzerland, (2) if similar findings on factors associated with free-riding can be found in Norway, and (3) the income distribution of the Norwegian retrofit subsidy recipients. We hypothesize that because we use close to identical methods, we will get similar results, 50% free-riding, and that the use of advice services and the perception of the implementer will predict free-riding. Finally, we hypothesize that the recipients of retrofit subsidies have a higher income than non-subsidy retrofitters and the average population.

With these hypotheses tested, policymakers will be able to make better-informed decisions regarding implementing household energy retrofitting policies. Firstly, it will shed light on the connection between subsidy threshold level and freeriding, optimizing subsidy schemes for more energy retrofitting, which will reduce energy demand. This helps communities and countries provide affordable and clean energy, and mitigate climate change, which is the core of UN sustainable development goals 7 and 13. Secondly, it will also give actual data to the theorized differences between high and low-income utilization of energy retrofit subsidies, providing direct help to UN sustainable development goal 10, reducing inequalities.

2. Methods

In May 2019, we sent an electronic survey to 2103 recipients who had received Norwegian subsidies for building envelopes or building energy counseling, which counted for the entire population of such subsidy recipients. This is similar to the Swiss sample, which consisted of households that had benefited from subsidies for insulation in the last two years. 2065 received the survey, and 315 clicked the survey link. Some left from the starting page, leaving 303 respondents with actual data and a final response rate of 14.7%. Although some e-mail accounts can be assumed to be inactive, this is a somewhat low response rate for a targeted demographic. Future studies, including incentives for survey responses to increasing response rates [90]), could be advantageous in confirming findings. As we sampled the entire population, we could not increase our sample size to increase confidence. The survey was originally collected for and funded by Enova SF, and some descriptive statistics can be found in a report [22]. There was no further involvement from the funding sources. Free-riding is not investigated in the report. The survey contacted everyone who had received subsidies for energy consultancy and/or energy retrofitting, only 183 stated they had received subsidies for energy retrofitting. Because of the small sample and specificity of some items such as the county, household-type, income, and retrofit activity, combined with the small population of Norway, we do not consider the dataset completely anonymous and can not publish the dataset. A list of all survey items, complete with the full statistical process featuring comments regarding smaller methodological choices, is available as a Stata "do-file" in the supplementary material.

2.1. Missing data treatment

Similarly to the study we replicate, respondents that inconsistently stated the subsidies had an effect on either scope, quality, or startup, but also agreed that the subsidies did not influence the retrofitting (n = 13), and vice versa (n = 6) were excluded from the dataset.

Because reporting frequencies were important to the study, the number of respondents was somewhat low even though the entire population was sampled, and data was most likely not missing completely at random, we applied multiple imputations [61] to fill missing answers (as suggested by Schafer & Graham [62]). Multiple imputation methods use statistical methods, usually regression, to estimate the most likely value for all missing data. This value, plus an uncertainty based on the confidence of the estimation, is input into the dataset. This process is repeated until several datasets are created. Then, the analysis is completed on all datasets, and the results are combined using Rubin's rules [61]. Although not as unbiased as having a complete dataset with no missing values, it is preferable to ignoring responses with missing data [62]. Because respondents often miss or purposefully ignore some items on a survey, having a complete dataset is impossible for most surveys, and multiple imputations are needed. Missing answers were imputed in a chained equation model in Stata v.16. For a full overview, see attached syntax files. Following the rule of thumb of applying a number of imputations equal to or larger than 100 times the largest fraction of missing information [74], which in our data was 0.26, we applied 50 imputations [82]. All Monte Carlo error estimates were less than 10% of the standard error of imputed variables, satisfying literature guidelines concerning a sufficient number of imputations [82].

2.2. Free-riding data

We applied methods as close as possible to Studer & Rieder [76]. Like the original study, our free-riding items were included in a larger survey distributed to recipients of retrofit subsides. We applied the same 4 point Likert scale (translated to Norwegian), and the same questions regarding the subsidies effectiveness on startup of the retrofitting, scope of the retrofitting, quality of the retrofitting, and a control question on whether subsidies had any influence on the retrofitting. Participants responding "agree" or "completely agree" on the 4 point Likert scale regarding whether the subsidies influence the scope, quality, or startup of the retrofitting were counted as non-free-riders in both studies (personal communication, Sibylle Studer, January 2020).

2.3. Income data

Income data were collected from three different sources. We decided to treat and consequently display these data as income deciles brackets rather than raw income. This allowed for a clearer comparison amongst data sources, especially concerning the population mean in Norway, and improve the anonymity of the respondents. The decile brackets on Norwegian household income according to the whole population, excluding student households or persons under 18 living alone, were retrieved from Statistics Norway [71]). Each bracket represents 239.825 households and is based on census data, which gives absolute numbers [71]. For the sample in our survey, we asked participants for their combined household income, which we later converted to income decile brackets. Finally, we retrieved income data from a representative sample of energy retrofitters in Norway surveyed in the same period [91], also uploaded as supplementary material. Income data from the surveys were self-reported. All sources list household income before tax. Income was adjusted according to the consumer price index to be comparable with each other. Because the three datasets were from different sources, we display them graph-wise with 95% confidence intervals regarding their imputed mean at each point to more clearly indicate where the differences between the samples are. Statistically, where the error bars representing 95% confidence intervals, do not overlap, the difference is $p < 0.05$. Since both datasets had 50 imputations, we also merged the two and tested if the lines as a whole were statistically different using ordered logistic regression. We also retrieved the mean McFadden's pseudo explained variance from all individual regression models across all 50 imputations to estimate the explanatory power. This number gives a solid indication of what share of freeriding behavior is explained by the model.

2.4. Differences in operationalization

Some independent variables differ from their operationalization in Studer and Reider (2019). The variable 'advisory service utilized' can naturally not represent the same advisory system as in Switzerland, as the systems are different. In our study, we measure whether participants used the "Enova answers" service. We judge this measurement to be very close to what the original study measured, described as a "cost-free, publicly funded energy advice services" [76]. As we wanted to keep the survey short and needed to include several items for a summarizing report [22], some compromise had to be made regarding the perception of the implementer index. Instead of basing it on 11 items on whether the implementer was cooperative, efficient, friendly, etc. (as done in the original study), we based our index on five items on the dialogue, information, and whether the subsidies should continue, shown in the appendix. Although they are different, we believe they should represent roughly the same underlying attribute.

2.5. Uneven group-sizes

Even though we expect a 50:50 distribution between free-riders and non-free-riders, there is a possibility that the distribution will be skewed to one side. In the event of uneven distribution, our statistical power will be reduced because one of the groups will be smaller. In the case of uneven distribution, we will eliminate predictor variables (as suggested by Tabachnick & Fidell [77]) allowing one predictor variable for every 7 outcome events per predictor variable, starting with variables that showed significant results in the original study [76]. Problems related to logistic regression are uncommon when it reaches 5–9 outcome events per predictor variables [79].

3. Results

Using similar methods, we find substantially different free-riding prevalence than Studer and Rieder [76]. See Table 2 for details. Results indicate free-riding on energy retrofits subsidies in Norway is low.

Because the frequency of free-riding is low, the free-riding group consists of, on average, 16.7 participants across imputations. Therefore, we reduce the number of regression variables to the utilization of advisor service, and the perception of the implementer.

Regression results, seen in Table 3, suggest that utilizing the advisory service and having a favorable perception of the implementer (Enova) is associate with more effective subsidies, as in no free-riding.

Income data suggest that amongst Norwegian energy retrofitters, households that receive subsidies on average belong to a higher income decile (M = 7.8 SE = 0.27) than households that retrofit without subsidies (M = 6.7 SE = 0.12), which again belong to a higher income decile than the population average (M = 5.5). This is illustrated in Fig. 1. Cumulatively counting the estimated percentile of subsidy recipients according to income decile starting from the top income decile gives 30, 50, 67, 83, 88, 89, 91, 92, 93, 100%. Ordered logistic regression shows income decile distribution is different between subsidized and non-subsidized retrofitters (OR = 2.78 SE = 0.56 $p < 0.0005$).

Table 2
The proportion of reported effectiveness of subsidies between findings.

The subsidies contribute to...	Frequency (SE) N = 164	Studer and Reider (2019) N = 588
Total at least one effect = effectiveness beyond free-riding assured	90%	50%
No effect = no effectiveness assured, free-riding behaviour	10% (0.03)	50%
Decision to renovate (only)	1% (0.01)	3%
Increase in quality of renovation (only)	4% (0.02)	8%
Increase in scope of renovation (only)	4% (0.02)	4%
Decision to renovate and increase in quality	5% (0.02)	9%
Decision to renovate and increasing in scope	1% (0.01)	1%
Increase in quality and scope	37% (0.04)	8%
Decision to renovate and increase in quality and increase in scope	37% (0.04)	14%
Incomplete answers but at least one effect	*	3%

* Not applicable as missing answers were replaced using multiple imputations.

4. Discussion

Our findings show that household energy retrofit subsidy free-riding in Norway is low relative to Switzerland. Where a survey finds 50% free-riding in Switzerland, our replicated survey finds 10% free-riding in Norway. The use of the advisory service and having a favorable perception of the implementer is strongly associated with not free-riding. Additionally, the subsidies are given primarily to high-income households, both relative to the population average and energy retrofitting households in general.

4.1. Free-riding frequencies

Overall, the amount of free-riding on retrofit subsidies in Norway seems to be one-fifth of the Swiss free-riding rate, but some nuances are important to note. Firstly, the proportion of free-riders in the two countries differs regarding the influence on the decision to retrofit, quality, and scale. The smallest difference is found in the decision to retrofit category, where 44% of Norwegian respondents state the subsidies made a difference, versus 27% of Swiss[3]. This is contrasted by the largest difference, found in retrofitting scale, where 79% of Norwegians state the subsidies made a difference, versus 27% of Swiss. For quality, 83% of Norwegians stated the subsidies made a difference versus 39% of Swiss. We believe that the differences regarding quality and scale stem from the higher threshold for receiving Norwegian subsidies, compared to the Swiss. With the high threshold, the original project needs to modify both quality and scale to be eligible for subsidies, and is changed thereafter. If the household realizes that they cannot reach the threshold for receiving subsidies, few or no changes are made. An important factor is probably that the Norwegian subsidy requires all parts of the house to be retrofitted, while the Swiss generally do not.

Regarding the smaller difference concerning the decision to retrofit, it is likely this difference also stems from the threshold difference. Free-riding could be much higher in small-scale retrofits,

[3] Percentages are calculated by adding up categories in table 1.

Table 3
Logistic regression on effects on the effectiveness of subsidies beyond free-riding. Model p = 0.0029. Mean McFadden's R2 = 0.173.

Independent variables	Range	Odds ratio (se)	Significance level
Advisory service utilized	0–1	5.18 (3.50)	0.015
Perception of the implementer index	1–7	2.20 (0.60)	0.004
Constant		0.04 (0.07)	0.049

which are not part of the Norwegian sample. Free-riding in large-scale retrofits could therefore be similar between Norway and Switzerland.

As the high threshold Norwegian subsidies seem to have an especially large effect on the scale and quality of retrofits, they are most likely very effective in preventing technical lock-in. Technical lock-in refers to the idea that further energy retrofitting is less likely to start once a recent building retrofit has been completed, thus "locking in" the current energy standard. Although some researchers stress that small scale retrofits are associated with more retrofitting [91], the established consensus suggests exclusively subsidizing large-scale retrofits that aim for a high energy standard to avoid problems associated with technical lock-in (e.g. [56,81]. This is especially important in colder climates, where high energy standards usually save more energy than in warmer climates [3].

4.2. Predicting free-riding

The use of the advisory service and having a more favorable perception of the implementer is associated with lower free-riding. This is similar to the findings of Studer and Rieder [76], suggesting this association is not restricted to one country. Contrary to the for the most part causal interpretation by Studer and Rieder [76], we believe these findings are heavily influenced by how much the participant "liked" the processes. This is especially true for the perception of the implementer index. According to associative learning mechanisms such as evaluative conditioning [11,32], if a household had an unfavorable experience during the retrofitting and subsidy process, this feeling will be associated with the entire process, including its implementer. For example, a household could experience that the retrofitting process was tiresome, overly bureaucratic, or did not achieve the energy-saving indicated because of the rebound effect [65]. Consequently, unfavorable emotions concerning this will be associated with the implementer *and* the effectiveness of the subsidies [73]. Households that have a unfavorable view of the implementer will therefore also report the subsidies to less effective, resulting in an association between non-free-riding and a favorable perception of the implementer, as the findings show.

The use of the advisory service could lead to less free-riding, but a complete causal relationship is still unlikely. The statistical association between the two could be caused by households that already had concrete plans for projects which surpassed the subsidy threshold did not utilize the advice service. This leads to an association between free-riding and utilization of advice services, where the latter does not lead to the former. Although households with smaller projects could utilize the advice service to increase the scope of their retrofit, which would be a causal relation, this effect is most likely not as strong as the regression effect size suggest. With the current evidence, it could be said that it is more likely than not that advisory services reduce free-riding, but more research is needed to establish this claim.

4.3. Income differences

Our results show that which households are being subsidized when conducting energy retrofitting is heavily dependent on the

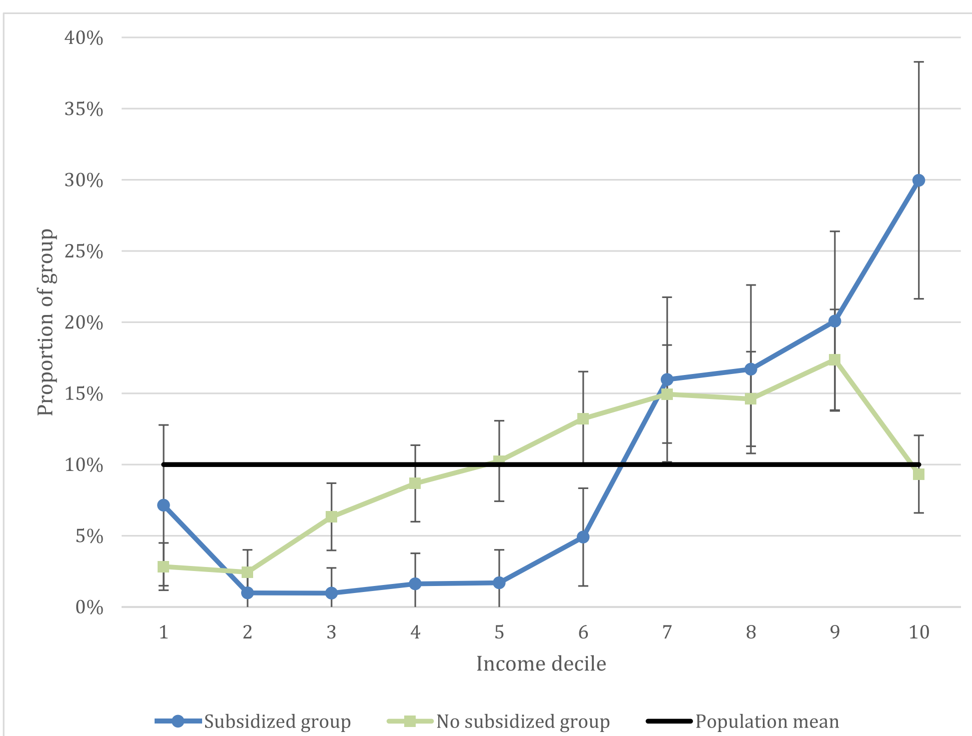

Fig. 1. The figure shows the income distribution within three groups. The population average (in black), people who have conducted energy retrofits without subsidies (in yellow squares), and those who have received energy retrofitting subsidies (in blue circles). Income decile 1 is the 10% poorest households, while income decile 10 is the 10% richest. Error bars represent 95% CI, non-overlapping error bars indicate statistically significant differences. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

decile income bracket of the household. In general, poorer households are receiving fewer subsidies. The thirds, fourth, fifth, and sixth income deciles receive statistically significant fewer subsidies compared to their rate of retrofitting, and the tenth income bracket is receiving significantly more. Additionally, there is a trend for the seventh, eighth, and ninth income brackets to also receive more subsidies relative to their retrofitting rate in the lower brackets. There is a linear relationship regarding the income bracket of the household and their rate of retrofitting, except for the highest income bracket. We hypothesize this is because the richest income bracket buys and lives in houses that are in no need of energy retrofitting, or are financially and environmental-consciously unaffected by high energy bills. There is a negative correlation between income and environmental concern [9], which indicates that richer households to a lesser extent retrofit for environmental reasons.

Several factors related to the subsidy policy design are important for its uneven distribution amongst income deciles. Firstly, Norwegian households must already have the financial resources to raise the scale and quality of the retrofitting, and the energy retrofitting must be completed through an external contractor. Therefore, we judge it as very likely that the 1-6th income deciles to a lesser extent have the financial resources to raise the scale and quality of their retrofits to be eligible for subsidies. As a consequence, the quality and/or scale of non-subsidized retrofits are not affected. Secondly, lower-income households likely implement the retrofitting themselves to a larger extent, with limited or no outside contractors as the households do not have the financial resources to outsource the retrofitting. Nonetheless, performing the retrofitting through other means than through contractors makes the household non-eligible for Norwegian subsidies.

Loans, or subsidized loans, seem like an intuitive way to help the lower six income deciles utilize the subsidies, but the literature suggests both have problems. Traditional means of financing energy retrofitting have issues (summarized by Hill [31]) where investors are hesitant to invest due to factors such as, but not limited to, volatile energy prices, risk aversion, and long payback periods. These issues indicate that unsubsidized large-scale financing of energy retrofitting is still a somewhat unrealistic possibility. Subsidized loans have also been subject to criticism. The most prominent issues are not increasing actual retrofitting rates compared to regular subsidies, and being subject to free-riding [7,38]. Walls [80] summarizes subsidized retrofit financing as very cost-effective, but low impact on actual retrofitting rates.

Finally, implementing subsidy income restrictions to combat the uneven distribution should be done with caution. Currently, household retrofit subsidies are not subject to stigma, such as public welfare [21,88,89]. Introducing a household income cap on receiving subsidies will most likely create an association between the subsidies and low socioeconomic status. Households could choose not to pursue the subsidies, including the minimum standards they include, as they do not wish to associate themselves with the low status of the subsidies and the following energy standard [18]. In a worst-case scenario, high and medium-income households could purposefully avoid retrofitting to a high energy standard because these buildings are associated with a low socioeconomic status. While it is difficult to predict cultural and normative change, the psychological research supporting such an outcome definitively exists [4,5,6,32].

4.4. Ethics of subsidy distribution

Several ethical issues are related to the skewed distribution of retrofit subsidies. It can be said that the success of a subsidy program largely depends on its goals. If the subsidies are meant to increase retrofitting rates in low-income households by making them more affordable, this distribution is negative. If the subsidies are meant to push the quality and scale of the more expensive retrofits, so that these methods become available to everyone, a sort of "trickle-down technology", it could be favorable. As stated in section 1.1, this is similar to the stated strategy of Enova. Therefore, it could be said that concerning their stated goal, the income distribution is not negative. But this could be disputed because if it is true that higher-income households often live in larger houses, it is usually low-income households who inhabit older and less efficient homes, which require more extensive and expensive retrofits as calculations of annual space heating requirements for houses in the UK building stock e.g. show [52]. Additionally, this effectively means Norway, in practice, does not have a subsidy scheme for energy retrofitting for low and medium-income households. More likely than not, this is an unintended side effect. Several aspects concerning energy justice are relevant concerning this.

As pointed in the introduction, scholars are increasingly arguing for the need for a just energy transition [30,45]; (Pellegrini-Masini et al., 2020) which is considered to be resting on the concept of energy justice [46,53,69], defined as "a fair and equitable process of moving towards a post-carbon society" [45]. Energy Justice and the just transition are centred on the three tenets of energy justice: distributional justice, procedural justice, and recognition justice, which mean, respectively, equitable distribution of energy services, inclusive democratic processes of energy policymaking, and the recognition of the rights and need for inclusion of especially disadvantaged social groups [46]. The justice arguments for a fair energy transition are rooted not only in equalitarian ethical arguments, but also in social and environmental considerations [54]. Arguing on empirical grounds, it has been stated that equitable distributions of goods appear to facilitate sustainable societies [83,84] while inequality appears to exacerbate carbon emission pollution [42]. While, with specific regards to energy and the future of energy systems, it has been warned that prosumerism and microgrids will mostly benefit those citizens that can afford new technologies [86], thereby fostering inequality and hindering the transition towards sustainable energy. Scholars [28,63] have shown that German network charges aimed at grid expansion to integrate renewables and the cost of feed-in tariffs supporting renewables have increased economic inequality in Germany. Growing inequality therefore risks becoming a byproduct of regressive policies adopted to facilitate the energy transition. In the specific case that we have presented, it could be argued that low-income households cannot implement retrofits or at very least their retrofits do not match for their entity or type those covered by subsidies, thereby excluding those more in need of energy cost saving actions and preventing them from accomplishing their environmental aspirations. Ultimately this regressive policy could contribute to a problem of energy vulnerability described as "the propensity of an individual to become incapable of securing a materially and socially needed level of energy service in the home" [8]. Although this might appear as an unlikely circumstance in a wealthy country like Norway, research shows otherwise: 2.7% of Norwegians in 2018 were in arrears in paying their utility bills [15], July 30), 15% of Norwegians in 2016 declared to consider themselves vulnerable with regards to the energy sector and of those considering themselves in such condition, 7% attributed the cause to their financial situation and 3% to their employment situation [14].

4.5. Context and further research

That a higher threshold for receiving subsidies most likely leads to lower free-riding must be seen in the context of other research. This is only one finding in a plethora of other factors that should be considered when designing retrofit subsidies (e.g., [1,24,33,48]).

For example, it is likely that a household's self-efficacy regarding using the subsidies to retrofit is significantly affected by the subsidy threshold. Self-efficacy is mostly referred to as "...a personal appraisal of one's capability to mobilise the motivation, cognitive resources, and behaviour required to cope with a prospective situation" [43], and has shown to influence several behaviors [51,66,78]. Because the Swiss system has a lower threshold, the self-efficacy related to receiving subsidies for energy retrofitting is likely higher in Switzerland. This should, in turn, lead to higher absolute rates of retrofitting caused by the subsidies. This is, of course, difficult to test, as other factors than the subsidy program affect the total retrofitting rate, and teasing apart the effect of the retrofitting program is challenging. But as this article argues, a low-threshold subsidy system leads to more free-riding, so the payoff regarding lowering the threshold must be carefully evaluated. To determine ideal thresholds for retrofitting subsidies is outside the scope for this paper but should be a fruitful area for further studies. A modeling approach focused on a behavioral model regarding energy retrofitting (eg. [41]) should prove especially useful. Similarly, excluding higher-income households from access to the subsidies could prove initially beneficial, but the possibility of shame and, therefore, underutilization should be first thoroughly explored.

Finally, the research should be extended to other places with similar cultures. We especially suggest the UK, which has received considerable research on its housing energy retrofitting policies [26,50,59,60,67,85]. Estimating UK free-riding compared to other countries is especially interesting considering its unique Supplier Obligation program (for an overview, see [58]).

4.6. Conclusion

Our findings show that low amounts of energy retrofit subsidy free-riding are present in Norwegian households, which is most likely connected to the high threshold for receiving these subsidies. Although a high threshold leads to larger scale retrofits that are more cost-effective, policymakers aiming for low free-riding by raising the threshold for receiving subsidies to achieve this must take into account that this also most likely both lowers the total amount of retrofitting caused by the subsidies, as well as focus the subsides on high-income households. Subsidizing high-income households raises not only ethical concerns, but as inequality appears to exacerbate carbon emissions, this counteracts the very problem the subsidies were meant to address in the first place. Our findings suggest that the availability of a free advisory service could lower the prevalence of free-riders and increase retrofitting rates. However, more research is needed to claim this confidently. Finally, we argue there is little support for claiming that raising the public perception of the subsidy implementers leads to less free-riding.

Replicating the same inventory measuring subsidy free-riding from Switzerland in Norway, we find the prevalence of free-riders to be much smaller, only 10%. Comparing the policies of both countries, we propose that the threshold for receiving subsidies is key in explaining this difference. Similar to Studer and Rieder [76], we also find that using advisory service and having a better opinion of the implementer is associated with lower free-riding. We argue this association could be caused by confounding variables, making the interpretation of how much of the association can be explained by causality difficult. Additionally, we find that the recipients of Norwegian subsidies are heavily concentrated amongst the higher-earning households. Although this is not in conflict with the overall stated goal of the subsidies, to subsidize new technology that is yet to become market competitive, we argue this widens inequalities in society, which is in itself an indirect source of carbon emissions, as well as impedes energy justice. To either make the subsidies more accessible or restrict the subsidies to low-income households could be an option. Still, careful attention must be directed to freeriding numbers and the possibility of shame associated with the subsidies.

Funding

This work was supported by the European Commission Social innovation Modelling Approaches to Realizing Transition to Energy Efficiency and Sustainability (SMARTEES) project [grant number 763912]; and partly by Enova SF, Trondheim, Norway [Project SID 09/1914 and SID 18/11690]. The financial sponsors played no role in the execution, analysis and interpretation of data, or writing of the study.

CRediT authorship contribution statement

Lars Even Egner: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Christian A Klöckner:** Funding acquisition, Supervision, Writing – review & editing. **Giuseppe Pellegrini Masini:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank Amarasinghage Tharindu Dasun Perera for his help regarding the literature search on Swiss Subsidy policy, and Sabine Hirsbrunne from the Swiss Federal Department of the Environment, Transport, Energy and Communications, for help in clarifying some aspects related to the same literature.

Appendix A

Table 3. Perception of the implementer index.

Item	Range
Information regarding the subsidy program has been good.	1–7
Information regarding the subsidy program has been easily accessible	1–7
Information regarding the subsidy program gave an impression that fits my actual experience with the program.	1–7
The dialogue with Enova has been good.	1–7
Enova's subsidy program should continue.	1–7

Principal components analysis load the first component with eigenvalue 3.18 and the second component with eigenvalue 0.848. This strongly suggesting one underlying component. The scale generated from the components has a Cronbachs Alpha of 0.85.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2021.111542.

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