Informally Sourced Solid Fuel Use: Examining its Extent and Characteristics of the Users in the Residential Sector in Ireland

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Abstract

Developing effective policy solutions to transition away from the use of solid fuels for residential heating purposes can be hindered by the lack of reliable data on its use. One such issue is the extent of informal solid fuel use, that is, consumption from sources outside of formal commercial channels. This is an area which has been largely ignored in previous empirical research. Using a survey of residential solid fuel users, the extent of solid fuel use in the residential sector in Ireland from informal sources for two fuels, sod peat and wood, is quantified. Sod peat is found to be almost exclusively sourced informally while just over half of wood use is estimated to be sourced by households in this way. Factors including location, income, being a primary user of the fuel and having strong cost motivations all effect the probability of sourcing solid fuels informally relative to formal sources. The sizeable extent to which informal sources of solid fuels are used in Ireland arising from the analysis in this paper, highlights the potential for substitution to this unregulated alternative. This should be carefully monitored for effective implementation of new and existing solid fuel regulations.

JEL Classification: Q40, Q50, R20

Key words: solid fuels; residential energy use; informal fuel sources; peat; wood

1. Introduction

Air pollution is becoming a leading risk factor for early deaths worldwide. Household air pollution resulting from the burning of solid fuels is a significant contributor to this, accounting for approximately a third of all air pollution deaths worldwide (Health Effects Institute, 2020). The World Health Organisation (WHO), estimate that 3.8 million people a year die prematurely from illnesses attributable to the air pollution caused by the inefficient use of solid fuels, mainly from cooking (WHO, 2021). Although frequently put forward as an issue which primarily effects low-income countries, the negative effects associated with air pollution are also present in many developed European counties, where the burning of solid fuels for space heating purposes through open fires or stoves or other heating systems is more commonplace. Research has shown that residential solid fuel combustion is an important contributor to poor air quality in many European cities and regions (Cincinelli et al., 2019; World Bank, 2019; Chakraborty et al, 2020; Kukkonen et al, 2020; Lin et al., 2019; Olsen et al., 2020; Wenger et al, 2020), presenting significant risks to people's health (Amegah and Jaakkola, 2014; Bailey et al., 2019; World Bank, 2019; Maher et al., 2021; Orru et al., 2022) and contributing substantially to health-related social costs (Kortekand et al., 2022). An estimated 417,000 premature deaths occurred in Europe in 2019 due to long-term exposure from fine particulate matter ($PM_{2.5}$) emissions (EEA, 2021), much of which is attributable to the combustion of solid fuels in households (Chafe et al., 2015; Amann, Cofala, Klimont, Nagl and Schieder, 2018). Recent research by the OECD has also found a causal link between air pollution and economic activity in European countries with increases in $PM_{2.5}$ concentrations leading to reductions in real GDP in the same year due to reductions in output per worker as a result of absenteeism at work or reduced labour productivity (OECD, 2019). Other research has also found that exposure to air pollution can lead to greater work absenteeism and thus lower productivity in European countries (Holub et al., 2021; Bruyneel et al., 2022).

Ireland is an example of a developed European country where solid fuel prevalence in the household sector is at a high level. Eurostat figures indicate its share of solid fuel use in the residential sector to be 11.7%, a figure which ranks second behind Poland (27.4%) among EU-28 countries. For space heating purposes only, the share of solid fuel use is even higher at 17.6%. The Irish Environmental Protection Agency (EPA) has cited the use of solid fuels, such as wood, peat and coal, as a leading contributor to fine particulate matter ($PM_{2.5}$)

concentrations across cities, towns and villages in the country (EPA, 2021). Research by Lin et al. (2018), found evidence of extreme episodic levels of air pollution in Dublin city during the 2016/2017 winter season due to the use of peat and wood. The European Environment Agency (EEA) suggests that exposure to $PM_{2.5}$ emissions caused 1,300 premature deaths in Ireland in 2019 (EEA, 2021).

The task of designing policy to support a transition away from the use of solid fuels faces several obstacles however due to the complexity of the market. Other fuels which are commonly used to satisfy a household's energy needs, such as gas, electricity or oil, are easier to observe and quantify, as they are supplied through pipes, fixed lines or in bulk quantities. In contrast, the sources of solid fuels are much more varied and therefore consumption can be much more difficult to monitor. Solid fuels can be purchased from legal commercial suppliers and fuel merchants, but they can also be sourced informally through grey markets from unregistered traders e.g. private sellers such as farmers or landowners. They can also be acquired for free off one's own land through the collection of foraged wood or wind-blown trees. In Ireland, the harvesting of peat bogs and supply of sod peat is another commonly used indigenous source of solid fuel energy to many households that own or rent peat bogs. Sod peat is also often purchased informally by households that do not own peat bogs[1].

Providing a means to estimate the extent to which households source solid fuels informally is important for several reasons. In developing countries, researchers have pointed to issues related to the degradation of open access forests as a motivation for examining the extent of fuelwood collected from these sources (Jumbe and Angelsen, 2011; Beyene and Koch, 2013; Jagger and Shively, 2014; Kegode et al., 2017; Yang et al., 2020). Ireland faces similar issues in relation to the protection and conservation of important peatland habitats under the EU Habitat's Directive. This has resulted in cessation of peat extraction from bogs which have been designated as Special Areas of Conservation (SACs) or Natural Heritage Areas (NHAs). A clearer understanding of the household characteristics of those engaging in informal usage

[1]It is difficult to describe the range of sources that is being examined in this paper under one suitable heading. The fact that there is no agreed title from the limited amount of previous research does not help. The word 'informal' has been used in previous research (Defra, 2020) and is plausibly the most appropriate. This will be used throughout the rest of the paper. Other descriptions include 'non-traded', which is used by the Sustainable Energy Authority of Ireland, but may not be as appropriate, given that trading does occur within this sector, albeit in an informal manner, outside of legal commercial suppliers and fuel merchants.

can also help to gauge the possibility for substitution between formal and informal energy purchases which could provide insights into how a cleaner energy transition can occur (Li et al., 2019). Finally, data collected from this sector can help to provide better statistical information on energy use which can update national energy balances and inform policy on air quality interventions (Defra, 2020; Romanach and Frederiks, 2021).

The paper addresses several gaps in the existing knowledge in this area. Although there is some research from developed countries which examines informal solid fuel use (Defra, 2020; Romanach and Frederiks, 2021), the question of what type of activities constitute participation in this sector remains unclear. This paper provides a strong contribution by outlining a method to capture the extent of informal sources of solid fuels. It sets out a broader range of possible informal sources in comparison to previous research, and also shows that within the informal sector there are sub-definitions of categories which merit individual scrutiny in themselves (i.e., grey and indigenous use). The paper is also one of the first to examine the characteristics of those who source solid fuels informally. As will be outlined in the next section, there is a large volume of research on officially recorded solid fuel use, but in contrast there is little to no research on the characteristics of informal solid fuel users, in terms of for example, income levels or age. This paper also advances on previous research by examining whether differences exist between formal and informal solid fuel users in how they respond to policies which aim to reduce the use of solid fuels. Whether informal solid fuel users have similar preferences to formal solid fuel users could be important for the design of policy in the area.

While the value added of this research to countries using solid fuels is significant, the relevance to Ireland is particularly strong. Besides the fact that the prevalence of solid fuel use is high in Ireland and a comprehensive examination of informal solid fuel use has not been carried out before, this research is also timely as the Irish government is currently implementing new solid fuel regulations to address instances of poor air quality. Existing solid fuel regulations in Ireland mainly cover the ban on the use of smoky coal in large urban centres, but new regulations will seek to increase the range of solid fuels that will require minimum environmental standards, including wood and peat, and to broaden existing regulations so that they apply across the entire state rather than designated urban areas (DECC, 2021). Ireland is also developing its first National Clean Air Strategy to establish a policy framework to reduce air pollution emissions from its main sources. An examination of informally sourced solid fuels is therefore timely to assess how effective the new regulations will be especially if formal and informal solid fuel users are found to respond to policy incentives in different ways.

The analysis that is presented is based on a survey of Irish households carried out in early 2020. Information regarding the types of fuel used for space heating, including solid fuels such as coal, peat and wood, the sources of these solid fuels, as well as the characteristics of those households using formal or informal sources of solid fuels was collected in the survey.

2. Existing Research Examining Informal Sources of Solid Fuels in the Residential Sector

A significant amount of research on the sources of solid fuel energy for householders can be found for lower income countries and regions in Sub-Saharan Africa and South Asia. This is not surprising given the dependence that these countries have on solid fuels for cooking. Some studies examine the extent to which households use informal sources of fuelwood only, such as forests based on different types of ownership status and tree species (Jumbe and Angelsen, 2011) or sources of fuelwood from forests versus savannahs versus croplands (Jagger and Shively, 2014) or from forests versus farmlands (Singh et al., 2021). Other researchers make the more distinctive differentiation between purchased fuelwood from markets and collected or self-produced fuelwood (Beyene and Koch, 2013; Behera et al., 2015; Jagger and Perez-Heydrich, 2016; Kegode et al., 2017; Yang et al., 2020). In these studies, the majority of fuelwood is collected or self-produced by households with the proportion of fuelwood purchased from markets being small, usually around 10%, with the exception of studies by Behera et al. (2015) and Yang et al. (2020), where it was estimated to be within a range of 20% to 30%.

While the research on solid fuel use and the sources of solid fuel energy is generally concentrated on lower income countries and regions, the issues highlighted, particularly in relation to improving access to cleaner sources of energy and the harmful effects associated with poor air quality, are also applicable to developing countries that are large users of solid fuels. As Kerimray et al. (2017) note, the WHO’s assessment of the burden of disease from household air pollution in developed countries with high use of solid fuels for space heating, may in fact be underestimated, given that the WHO's methodology relies on survey data that captures the extent of solid fuel use for cooking purposes only.

A volume of research into the factors determining the use of solid fuels in developed countries currently exists (see Laureti and Secondi, 2012; Couture, Garcia and Reynaud, 2012; Song et al., 2012; Özcan et al., 2013 and Fu et al., 2014 for an Irish example), but studies examining the ways in which households in developed countries source their solid fuel energy is much more limited. This is because the sources of solid fuel energy in developing countries are more likely to be market based but also because of the recognised difficulties in obtaining reliable information on informal sources, particularly in the domestic market for wood (CA-RES, 2012). Studies which do examine informal sources of solid fuels, tend to rely on surveys of households undertaken by government bodies and national statistical agencies with questions which specifically relate to these issues. Examples are present for some Nordic countries for the domestic use of wood, given its prevalence as a heating fuel in these countries. A 2015 survey of Danish householders' wood consumption found that 48% sourced wood from private gardens and wind-blown tress, while 14% purchased directly from the forest and 18% from other firewood dealers, such as hardware stores (Danish Energy Agency, 2016). An older study of Finnish households which examined the origin of fuelwood consumed in small-scale housing in 2007/2008, found that 60% of households used their own forest holding or some other own source, 17% obtained the wood free of charge from another source and 23% purchased from other sources (Natural Resources Institute Finland, 2009). In a more recent study using survey data from Finnish households, 29% of the sample were recorded as having access to firewood from family sources (Räihä, and Ruokamo, 2021).

A small number of other European countries have carried out similar surveys. In 2015, the UK Department of Energy & Climate Change carried out a domestic wood use survey as a special feature to its regular energy trends publication. The survey focussed on providing accurate estimates of consumption levels of wood but also provided information on the sources of wood. It was estimated that 31% of domestic wood fuel was sourced by households from informal or what they term as the "grey" wood market (DBEIS, 2016). In a more recent survey by the UK Department for Environment, Food and Rural Affairs, it was estimated that 32% of indoor burners who had burned wood in the past week had accessed most of it for free while 8% had accessed it through informal sources e.g. bought from landowner or farmer (Defra, 2020). Both of these reports highlighted the UK's commitments to reduce air pollution concentrations and the publication of its own Clean Air Strategy as important policy drivers for carrying out the research.

In a similar study on residential firewood consumption in Australia (Romanach and Frederiks, 2021), the authors reported self-collection to be most commonly cited way of sourcing firewood (reported by 55% of firewood users), followed by purchasing firewood from a commercial supplier/shop (33%), buying it from a private seller (31%), and receiving firewood for free from others (28%). In a study of Italian households, Caserini et al. (2007) reported that 49% of households claim they self-produced their own domestic wood supply, 48% bought it from a seller/farmer, 8% received it free of charge and 8% bought it from a shop. An updated study by the Italian National Institute of Statistics undertaken in 2013, found that just over half of Italy households consuming firewood either self-produced or collected the wood (ISTAT, 2014). In an older study of US fuelwood users, Skog and Watterson (1984) find that only one-fourth of fuelwood was acquired through purchases with most cut by household members themselves. These studies, along with the UK studies mentioned previously, serve to illustrate that the extent of informally sourced wood is far from insignificant and warrants further examination in developed countries with high levels of domestic wood use.

While research on informally sourced solid fuels mainly focuses on wood use, this does not preclude the possibility that other solid fuels are sources in a similar way. In Ireland the use of sod peat (also commonly referred to as turf) for space heating has long been a tradition for many households. Its importance in serving residential energy needs has diminished in recent years as the use of oil and the expansion of the natural gas network has provided access to other alternative space heating fuels. It currently comprises a 4.5% share of final energy consumption in the residential sector (SEAI, 2021). While most of this use is confined to rural areas and particularly to the Midlands and Western regions in Ireland where the majority of peat bogs are located (CSO, 2021), there is some evidence to suggest that sod peat is also been used in urban centres, given the existing research on air quality in these areas (Lin at al., 2019). While peat in these areas can be extracted and sold on a commercial basis (in the form of peat briquettes or milled peat that has been mechanically dried and pressed under high pressure in a factory to form the briquette shape), many households also own their own bog which they harvest for their own personal use or sell (or gift) to relatives, neighbours and friends[2].

The Sustainable Energy Authority of Ireland (SEAI) is the body charged with collecting national and sectoral energy statistics in Ireland. In order to produce residential energy use statistics for sod peat and wood, the SEAI have mainly relied on industry experts and surveys of wood suppliers. The surveys tend to have poor response rates however and the SEAI have themselves acknowledged the difficulties in obtaining accurate data for these fuels and particularly the extent to which they are sourced informally (SEAI, 2018). The most recent estimate put forward by the SEAI for the extent of informal wood use, suggested that it accounted for 32% of wood energy in the residential sector (SEAI, 2018). For sod peat, the SEAI have not carried out an analysis of a breakdown between the extent that it is formally or informally sourced by households, focusing instead on the task of estimating the overall amount of sod peat that is used in the sector. In consultation with industry experts, the SEAI have assumed that overall sod peat use has remained constant since 2012, comprising approximately two-thirds of overall peat use in the residential sector, with peat briquettes making up the remainder (SEAI, 2018). As mentioned previously, there are reasons to be believe that sod peat is being used in urban settings and therefore being distributed through more formal channels. But more evidence needs to be gathered to quantify the extent to which this is occurring.

Research on the factors associated with sourcing solid fuels informally in developed countries is very limited. Most only refer to the role that location plays given that the closer you are to a fuel resource, the more likely you are to engage in collecting or harvesting that fuel yourself. The UK DBEIS survey on domestic wood use found that for most wood types, the proportion sourced from “grey” markets was greater for rural areas compared to urban areas, except for waste wood which was sourced informally in urban areas to a greater extent (DBEIS, 2016). In a similar vein, Romanach and Frederiks (2020) found respondents living in major Australian cities to report higher levels of firewood purchases while respondents living in more remote locations reported higher levels of self-collection. The more recent UK

[2] In 2020, Bord na Móna, the semi state body which oversees the developments of peatlands in Ireland, announced the end of all commercial peat harvesting and a move toward renewable energy, recycling, waste management, carbon sequestration and biodiversity conservation. Private harvesting for those with turbary rights is still permitted in peat bogs which have not been designated as Special Areas of Conservation (SACs), Special Protection Areas (SPAs) or Natural Heritage Areas (NHAs).

Defra survey suggested a possible price effect, with wood users tending to purchase rather than salvage when wood was cheapest (Defra, 2020).

Other researchers make implicit references about the likelihood of using informal solid fuel sources. Lindroos (2011) for example found that a little over half of households surveyed in Northern Sweden owned a forest and thereby had free access to wood. Forest ownership or living close to a forest is also found to increase the likelihood of using wood (Rouvinen and Matero, 2013; Glasenapp et al., 2019) while living in rural areas is almost universally found to have a positive effect on wood use (Arabatzis and Malesios, 2011; Song et al., 2012; Lillemo and Halvorsen, 2013). In Ireland, the presence of a nearby peat bog has been found to increase solid fuel use in that area and neighbouring areas (Fu et al., 2014) while the further a household is located from a peat bog the more likely they are to adopt gas for space heating (McCoy and Curtis, 2018).

The overview of the relevant literature in this section highlights the gaps in current knowledge. In the first instance, there is a general shortage of research and thus an understanding of informal solid fuel use in comparison to formal solid fuel use. Furthermore, although there are some studies which have previously examined the extent of informal sources of solid fuels, the analysis lacks the presentation of a consistent definition and comprehensive approach to examine the sector. A consistent definition can help to ensure comparability, not only across countries, but also across time if the focus of the analysis is just one country. An understanding of those households which are more likely to engage in sourcing solid fuels informally is also absent in the literature, with just some references to the role that location plays solely. Finally, estimates for the extent of the informal sector relative to the formal sector appear to be mainly based on the proportion of respondents that indicate they access solid fuels from these sources and do not attempt to measure to provide a weighted measure based on quantities used.

3. Data and Method of Analysis

The data used to capture the extent of informally sourced solid fuels in Ireland was taken from a broader online survey of household solid fuel use. The survey questions were developed by the authors and a global leading company in first-party data collection, Dynata, were employed to administer the survey. Dynata maintains a large online panel of approximately 107,000 demographically diverse Irish householders that are registered to participate in online surveys. The use of market research companies for data collection purposes has been undertaken in Irish academic research before (see Curtis et al., 2018) and is especially useful for obtaining large samples of hard-to-reach groups, such as primary users of solid fuels and more specifically those that source solid fuels informally. Respondents to the final survey were recruited via a quota sampling technique, that is households were selected into the final sample based on a specific characteristic, such as using a solid fuel as primary fuel. This was chosen to ensure that sufficient samples of solid fuels users were obtained to carry out a meaningful analysis. The final version of the survey was administered between February and March 2020 and 1,823 responses were collected in total, of which 1,043 households indicated that they used at least one solid fuel for space heating purposes[3].

To ensure the samples representativeness, quotas were also applied to households that used other fuels for primary heating purposes (e.g. natural gas, home heating oil) and those that used solid fuels to supplement a non-solid primary fuel (who will be referred to as supplementary solid fuel users). Consideration was also given to ensuring a representative spread of households across regions and the age of the respondent. The sample proportions from the online survey compare favourably to a similar representative survey of Irish household energy use carried out by the Irish Central Statistics Office (CSO), known as the CSO Survey on Household Environmental Behaviours (CSO, 2016), with similar proportions across heating fuels used, regional location, urban/rural location and dwelling age.

There are two main objectives to this study. The first is to quantify the extent to which solid fuels are sourced informally in Ireland. The second is to the examine the characteristics of those households that predominately source solid fuels informally versus those that predominately purchase solid fuels from commercial sources to identify any features that distinguish one from the other. This analysis includes examining differences in household and location characteristics as well as differences in stated policy preferences. As highlighted

[3] Prior to its launch, the survey was reviewed by external academics and energy experts. The feedback they provided and modifications to the questionnaire that were subsequently made helped to address issues of content validity. Between November 2019 and January 2020, the questionnaire was also piloted with 196 respondents to assess its face and content validity. After the pilot tests, refinements were made to the layout and structure of the questionnaire, as well as to question phrasing and response options. The pilot testing included open-ended response options that allowed respondents to provide detail about the sources of their solid fuels, thus ensuring that the formal and informal sources of solid fuels were accurately captured in the survey. The external evaluation and pilot survey also enhanced the reliability of the survey by ensuring the instructions and wording of questions were clear and concise throughout.

already, a difficulty in carrying out these objectives is that there is no agreed definition for what constitutes the informal solid fuel sector. Therefore, an established method of analysis that other researchers can follow is not available. Most of previous research in this area uses surveys to ask respondents to report where they source their fuel from using a list of possible options. This paper expands on this approach, but accounts for a larger range of possible informal sources and the non-homogenous nature of the sector.

Households that indicated they used at least one solid fuel for space heating proposes were presented with a list of possible options of where they sourced their solid fuel(s). The question was structured in such a way that households could choose one source or multiple sources for each solid fuel, but if they chose multiple sources, the proportions would have to sum to 100% before respondents could move on to the next question. Respondents were also asked to quantify the amounts that they consume of each solid fuel used[4] and these figures were weighted by the proportions for each source stated to provide a measure of the extent of informally sourced solid fuels based on quantities rather than on proportions. Two households may record similar proportions of informally sourced solid fuels but not necessarily similar quantities.

The list of options was presented to respondents in an unordered fashion and categorised under formal and informal sources after the data was extracted and not within the question (see table 1). Formal sources include purchases made from a fuel merchant or supermarket either locally or online, or purchases made from a fuel merchant or supermarket that are subsequently gifted (i.e., given for free) to the household. Informal sources are therefore defined as situations in which households obtain solid fuels outside of these channels. As can be seen from table 1, a wide range of informal source options are included. This helps to ensure that that as much of the solid fuel use in the informal sector is captured and thus improve the accuracy of the approach.

[4] Respondents were asked to quantify their daily use of solid fuels based on the number of standard receptacles and then this was converted into kilogram (kg) terms. This approach was chosen for a number of reasons including the possibility that respondents may find it difficult to provide accurate estimates for the weight or volume of formal and informal solid fuel deliveries which can vary substantially by transport mode (e.g. trailer size), respondents may also have difficulties recalling the quantities of solid fuel obtained in bulk delivery when the fuel was obtained some time ago, and the difficulty in determining actual consumption from bulk deliveries as solid fuel deliveries can be made in anticipation of heating requirements and thus may not directly relate to actual quantities used. In this survey a standard fireside bucket with specific dimensions was chosen as this is a commonly used item in Irish homes and as a consumption measure is less susceptible to the aforementioned issues.

As a key conceptual advance on the methods used in previous research, informal sources of solid fuels are divided into two types. Grey sources refer to situations where money is paid to a local household or individual who is a private seller while indigenous sources are situations where fuel is sourced for ‘free’ as it has been harvested/foraged/collected from one’s own land or is gifted to a household by family, friends, or neighbours who have harvested/foraged/collected from their own land. The key distinction between grey informal sources and indigenous informal sources is that a monetary transaction takes place with the former which covers the cost of harvesting, foraging or collecting that the individual cannot undertake themselves. An ‘other/unspecified’ category was also included to allow for other sources of solid fuels which did not come under the headings and descriptions presented in the question in the online survey.

Table 1. Formal and Informal Source Options and Descriptions presented to survey respondents

FORMAL:
Purchased locally from a supermarket, garage, general supplier or other company that specialises in supplying fuel
Purchased online from a supermarket, garage, general supplier or other company that specialises in supplying fuel
Gifted to you by family/friends/neighbours who purchased it from a supermarket/garage/general supplier/company
INFORMAL/GREY:
Paid money to a local household/individual (for wood only)
Paid money to a local bog owner/renter (for sod peat only)
Paid money to another household or individual sourced through other contact
Paid money to another household or individual sourced online
INFORMAL/INDIGENOUS:
Harvested from your own bog or rented bog (for sod peat only)
Gifted to you by family/friends/neighbours from their own bog or rented bog (for sod peat only)
Harvested from your own land or rented land (for wood only)
Gifted to you by family/friends/neighbours from their own land or rented land (for wood only)
Gathered, foraged or found by you e.g. in a local woodland (for wood only)
OTHER/UNSPECIFIED

The paper presents results for extent to which two solid fuels, sod peat and wood, are informally sourced. The use of wood as an energy source for household space heating in the EU has increased significantly in recent years. The proportion of households energy consumption for heating using wood in the EU increased from 13.3% to 21.3% between 2000 and 2018 (Odyssee-Mure, 2021). This is in the context of the EU’s drive to increase the amount of heat energy that is derived from renewables, including wood. Such an approach has drawn criticism in recent years however as the negative contributions of wood use to air quality and the over harvesting of forests are thought to outweigh any positive contributions to reducing carbon emissions (Searchinger et al., 2018; EEA, 2019). Most research on informally sourced solid fuels has concentred on wood but sod peat is a large indigenous fuel in Ireland, so it would be expected that there would be a significant informal element to this fuel also.

In the survey, wood is taken to include any manufactured or unmanufactured wood products and covers wood pellets, wood chips, wood logs, wood briquettes and waste, branched or foraged wood. Of the 1,043 households in the survey that indicated they used at least one solid fuel for space heating purposes, 292 households recorded the use of sod peat and 734 households recorded the use of wood[5]. Table 2 presents the samples proportions for each solid fuel examined in the survey by formal and informal source. As can be seen, most households indicate that they source sod peat from indigenous and grey sources solely while most households indicate that they source wood from formal and indigenous sources solely. While approximately 82% of sod peat users obtain their fuel from just one source, only 65% of wood users do similarly. Thus, approximately a third of wood users obtain this fuel from multiple sources indicating the different ways in which wood is supplied but also that households have opportunities to obtain wood from more sources relative to other fuels. Coal (divided into low smoke and other coal categories) and peat briquettes and also included for comparison purposes. These fuels are predominately supplied through formal channels with a small proportion of activity from grey sources in each instance[6]. Hence the focus is on sod peat and wood where a greater spread of activity occurs among the formal and informal sectors.

The second objective of the paper examines the characteristics of those households that predominately source solid fuels informally versus those that are more likely to purchase these fuels from formal sources. As previously stated, most of the research on household solid fuel use examines the characteristics of those households that choose solid fuel over other fuels such as natural gas, oil or electricity. The energy ladder model hypothesis (Leach, 1992) is commonly used as a conceptual framework in these studies. This model suggests that households move up an energy ladder from traditional fuels at the bottom (e.g. solid

[5] Respondents could pick multiple solid fuels when asked what fuels they used to heat their homes.
[6] Although interestingly, there is a slightly higher proportion of other coal which is obtained from grey sources presumably because this, in contrast to low smoke coal, is not subject to strict minimum environmental standards at the point of sale.

Table 2. Proportion of households using solid fuels by formal and informal sources

Number of Sources	Source	Low Smoke Coal[a] (N=530), %	Other Coal[a] (N=239), %	Peat Briquettes[a] (N=383), %	Sod Peat (N=292), %	Wood (N=734), %
1	FORMAL	79.2	70.3	79.4	12.3	34.1
1	GREY	4.5	6.7	4.2	29.8	7.2
1	INDIGENOUS (INDIG)				38.7	22.5
1	OTHER	1.3	0.8	1.0	1.4	1.4
2	FORMAL/GREY	10.6	19.2	10.2	2.7	2.3
2	FORMAL/INDIG				1.7	16.9
2	FORMAL/OTHER	1.3	0.4	1.6	0.0	0.8
2	GREY/INDIG				5.5	3.4
2	GREY/OTHER	0.6	0.4	0.3	0.0	0.1
2	INDIG/OTHER				0.0	0.8
3	FORMAL/GREY/INDIG				5.1	8.2
3	FORMAL/GREY/OTHER	2.5	2.1	3.4	0.0	0.0
3	FORMAL/INDIG/OTHER				0.3	0.3
3	GREY/INDIG/OTHER				0.0	0.1
4	FORMAL/GREY/INDIG/OTHER				2.4	1.9

[a]Coal and peat briquettes are assumed to not be available via indigenous sources

fuels) to modern fuels at the top (e.g. electricity) as income increases. Although a clear relationship between income and the choice of fuel has been found in a number of studies (Laureti and Secondi, 2012; Özcan et al., 2013), the emphasis on income as a leading determinant and the assumption that fuel transition occurs in a series of simple, discrete phases, has been criticised (van der Kroon et al, 2013). An alternative theory, based on energy stacking (Masera, Saatkamp and Kammen, 2000) has therefore also been used to explain household energy choices. This model assumes that transitions can occur but only in a partial way, that is, households use a combination of fuels which may include those at both the bottom and top of the energy ladder (Celik and Oktay, 2019).

The energy ladder and energy stacking theories can be used as conceptual frameworks for this study also. For example, it is plausible that as income increases, households may shift their fuel usage from traditional informally sourced solid fuels to more established solid fuels, or other modern fuels (e.g. natural, oil and electricity) obtained from formal commercial settings, in line with the energy ladder theory. In contrast, households may continue to use informally sourced solid fuels in combination with fuels obtained through formal channels to ensure a consistent and secure supply of fuel or to insulate against the effects of fluctuating energy prices or because of culture and traditional social practices (van der Kroon et al, 2013).

To examine the second objective, each household is categorised as either a formal or informal (grey or indigenous) solid fuel user based on whether the majority of their sod peat or wood consumption came from one of these sectors. In doing this an unordered categorical variable is generated which can be related to a set of house, household and location characteristics which were also collected in the survey. A clear choice for the estimation technique where the dependent variable is an unordered categorical variable is the multinomial logit model (MNL). To model an unordered categorical variable, a common starting point is the random utility framework (see Braun, 2010 and Curtis et al., 2018) which assumes that an individual (or household) attaches a utility level to each alternative and chooses the one that gives the highest level of utility. The utility of each alternative can be expressed as a linear function of observed individual characteristics i.e.

$$U_{ij} = X_i\beta_j + \varepsilon_{ij} \qquad (1)$$

where U_{ij} is the utility that individual i attaches to alternative j, X_i are the set of observed characteristics or explanatory variables based on individual i with associated estimated β_j coefficients and ε_{ij} is the error term. The probability that an individual chooses the alternative that gives the highest level of utility (alternative j) among all other alternatives k, can then be written as,

$$P\{alternative\ j\} = P\left\{U_{ij} = max\{U_{i1}, \dots, U_{iM}\}\right\}$$
$$= P\left\{X_i\beta_j + \varepsilon_{ij} > \max_{k = 1, \dots, M, k \neq j}\{X_i\beta_k + \varepsilon_{ik}\}\right\} \qquad (2)$$

The above probability can be simplified into a manageable expression, when the error terms ε_{ij}, are assumed to follow a Type I Extreme Value (or Gumbel) distribution. This leads to a probability representing the multinomial logit model (MNL) given by,

$$P\{y_i = j\} = \frac{exp\{X_i\beta_j\}}{1 + \sum_{k=1}^{J} exp\{X_i\beta_k\}} \qquad j = 0, 1, 2, \dots, J \qquad (3)$$

To ensure the probabilities across each alternative sum to one, the parameters specific to one alternative are set to zero. Thus, MNL slope coefficients are estimated for all but one of the alternatives.

Table 3 provides descriptive statistics for the explanatory variables used in the MNL models. Two location variables are included as explanatory variables, one which distinguishes households by extent of urban/rural location and the other by regional location. The expectation would be for differences to exist for urban/rural location on the basis that urban areas are likely to have greater access to formal commercial markets and rural areas to informal sources. The decision to include regional location is on the basis that sod peat use is also likely to have a regional effect, to capture the presence of peat bogs which are spread regionally across the country (Fu et al., 2014). As can be seen in table 3, there are noticeable regional effects for sod peat especially and rural effects for both solid fuels relative to the full sample of solid fuel users.

Whether a household uses sod peat or wood as their primary source of space heating or not, could also influence the propensity source solid fuels informally. Primary users may prefer to acquire solid fuels via more dependable indigenous or grey market sources and may also wish to keep large stocks of solid fuel to ensure a continuous supply (i.e. bulk delivery or harvest). In contrast, supplementary users may source fuels on an irregular basis and be less willing to engage in the labour and time intensive efforts required to obtain indigenous and grey fuels. They may therefore prefer to source smaller quantities of solid fuels via commercial outlets. In a similar way, households with strong cost motivations may prefer sourcing solid fuels via indigenous and grey market sources since these sources could be perceived to provide a cheaper means of acquiring solid fuel. To capture this, respondents to the survey were asked to state whether the cost of solid fuels relative to other fuels or energy sources was important in their decision to use solid fuels. Table 3 shows that cost motivations are strong for solid fuel users in general and even more so for sod peat users.

In line with the energy ladder theory, household income is included as an explanatory variable to see whether this influences the decision to source solid fuels formally or informally. A positive income effect for sourcing solid fuels formally might suggest support for the energy ladder hypothesis, this is, increases in household income could provide a means by which households transition away from sourcing fuels informally. The age of the household occupants and the age of the dwelling may also be influential factors given that research has shown a negative relationship between solid fuel use and age (Lillemo and Halvorsen, 2013; Özcan, Gülay and Üçdoğruk, 2013) using health concerns and ease of use

Table 3. Proportions of Households in the Solid Fuel Survey for the Samples of Solid Fuel Users, Sod Peat Users and Wood Users.

	Solid Fuel Users (N=1,043), %	Sod Peat Users (N=292), %	Wood Users (N=734), %
Location - Region			
Dublin	14.57	9.59	15.26
Border	14.00	13.70	13.35
Mid-East	11.31	9.59	11.31
Midlands	11.12	19.52	9.26
Mid-West	11.89	12.33	13.90
South-East	11.60	2.40	13.35
South-West	14.00	10.62	14.17
West	11.51	22.26	9.40
Location - Rural/Urban			
Rural (Pop <1,500)	45.64	53.42	50.82
Sm. Town (Pop 1,500<5,000)	20.71	22.60	17.98
Lrg. Town (Pop 5,000<50,000)	21.00	13.70	19.48
City (Pop >50,000)	12.66	10.27	11.72
Annual Net Household Income			
Under €20,000	20.04	21.58	17.57
€20,000–€30,999	18.41	15.75	18.53
€31,000–€49,999	28.48	32.53	30.25
€50,000–€78,999	22.24	18.49	22.48
€79,000 or over	10.83	11.64	11.17
Age of Oldest Adult			
18–34 years	11.31	12.67	11.17
35–54 years	43.91	46.58	44.01
55–74 years	26.46	24.66	27.25
75 years or over	18.31	16.10	17.57
Dwelling Age			
1980 or earlier	42.47	41.78	44.55
1981–1990	14.96	13.01	13.08
1991–2000	16.40	17.47	16.35
2001–2010	23.01	24.32	22.75
2011 or later	3.16	3.42	3.27
Primary User			
No (ref)	57.72	63.36	84.88
Yes	42.28	36.64	15.12
Cost Motivations for using Solid Fuels			
Not Important	38.06	26.37	34.60
Important	61.94	73.63	65.40
High Level of Knowledge of Impact of Solid Fuels			
No	60.12	52.74	56.27
Yes	39.88	47.26	43.73

as explanations. In contrast, informally sourced solid fuels would be considered a more traditional form of home heating which may be confined to those in older age groups and/or those living in older dwellings. It may also be the case that older occupants are supplied with solid fuels by family members or friends or neighbours rather than sourcing it themselves, although in this instance, it is equally possible that the original source could be formally or informally sourced. The proportions of sod peat and wood users in the categories of these two variables are reasonably similar, with sod peat users tending to be in the lower and middle income categories and of younger ages (based on the oldest adult).

Finally, knowledge of the adverse impact that solid fuels have on air quality and health may plausibly influence the choice of solid fuel source. Rouvinen and Matero (2013) for example, found that knowledge of levels of fine particle emissions from different residential heating systems reduced household preferences for solid wood fired heating. In contrast, Damette et al. (2018), found that a household which stated that they considered the environment when making decisions about their energy source, were more likely to choose wood. In the context of this study, more knowledgeable households may be willing to seek out better quality solid fuels from an environmental and health perspective, which are more likely to be found in formal commercial outlets. Households that are less knowledgeable and less concerned about solid fuel quality may be satisfied to use informally sourced solid fuels especially if other factors such as accessibility or cost are more important. In the survey, respondents to the survey were presented with three questions which gave two solid fuel options and asked respondents to indicate which one they consider to be the better choice for air quality and health, for example, dry/seasoned wood versus green/unseasoned wood. Based on the responses a knowledge variable was constructed[7]. Close to 40% of households using solid fuels answered all questions correctly with both sod peat and wood users more knowledgeable that the overall sample of solid fuel users.

4. Results

4.1 Extent of Informally Sourced Sod Peat and Wood

Table 4 displays the estimated average daily household consumption of sod peat and wood and proportionate amounts by formal and informal sources. Just over 90% of sod peat is estimated to be informally sourced with a larger proportion of this based on indigenous sources than grey sources. As previously mentioned, the SEAI do not provide any breakdown of their sod peat consumption statistics by how it is sourced by households, so this analysis represents an advance on previous knowledge. The estimates confirm anecdotal evidence that a significant proportion of sod peat is traded through informal grey markets (DECC, 2022) and also provides evidence that a proportion of sod peat, albeit small, is sourced through

[7] Specifically, respondents were asked to choose between (1) Low smoke coal and other coal (2) Dry/seasoned wood and green/unseasoned wood, and (3) Dry/seasoned sod peat and waste products (e.g. household waste). A dummy variable was created where one category represents those that answered all three questions comparing pairs of solid fuels from an air quality and health perspective correctly.

formal channels. This information can be useful in determining how much sod peat use could potentially be subject to new regulations (i.e., in formal settings) and how much would not (i.e., where sourced informally). The large share of informal use highlights the importance of this sector for this fuel and the extent to which much of its use will remain unregulated.

In contrast, the estimated proportions of formal and informal wood consumption are more evenly matched with slightly more stated usage of informal sources. Of the informal wood sector, indigenous sources are more than twice as large as grey sources. In comparing these estimates with previous attempts using Irish data by the SEAI, the extent of informally sourced wood in this study (52.5%) is significantly higher than the most recent estimate put forward by the SEAI (32%) (SEAI, 2018). This study therefore indicates a considerable underrepresentation of the extent of informally sourced wood based on previous appraisals. One of the consequences of this is the potential for an underrepresentation of the overall level of wood use estimated by the SEAI in their official residential energy use statistics[8].

Table 4. Average Estimated Daily Household Consumption of Solid Fuels (in kg) and Proportionate Amounts by Formal and Informal Sources (in %)

	Sod Peat *N*=292	Wood *N*=734
FORMAL	0.73 (8.2%)	2.88 (44.0%)
INFORMAL/GREY	3.30 (37.2%)	1.08 (16.5%)
INFORMAL/INDIGENOUS	4.70 (53.1%)	2.36 (36.1%)
OTHER/UNSPECIFIED	0.13 (1.5%)	0.22 (3.4%)

A further implication to the estimates in table 4 is for the proposed introduction of new environmental standards and regulations. With stricter regulations the possibility for increased substitution to unregulated fuels which are sourced informally is greater. The estimates in table 4 show that the sector is sizable so the potential for substitution is real. As a previous example of this, the SEAI in their most recent Energy in Ireland report (SEAI, 2021), speculate that the reduction in oil consumption in the residential sector between 2010

[8] Taking the values in table 4, the ratio of total wood use to total sod peat use is approximately three-quarters (6.54kg versus 8.86kg), whereas in the SEAI published statistics for residential energy use in 2020, the corresponding ratio is only approximately one-fifth (26ktoe versus 128ktoe) (SEAI, 2021). While the comparison is not necessarily a like-for-like one (i.e., kg's versus ktoe's) and its crudeness should be treated with some caution, it does indicate a possible underrepresentation of overall level of wood use in the SEAI data, due possibly to an underrepresentation of the extent of informal wood use, based on the findings from this study.

to 2014, may have been due to a number of factors including increases in oil prices, but also to greater opportunities for fuel switching from oil to informally sourced solid fuels, such as sod peat and wood. By providing a baseline for the extent of informal solid fuel use and a method of analysis for examining this sector going forward, the incidence of any substitution to these products can be carefully monitored.

4.2 Analysis of the Characteristics of Informal Solid Fuel users

The second objective of the study is to examine the characteristics of those households that engage in informal solid fuel consumption versus those that engage in formal solid fuel consumption to identify statistically significant differences between the two groups. Table 5 presents information on the number and proportion of households that are classified as either formal sod peat/wood users, informal grey sod peat/wood users and informal indigenous sod peat/wood users. This was determined based on whether the largest proportion of their sod peat/wood consumption came from one of these sources. Using this method most sod peat users can be categorised as obtaining this fuel from informal indigenous sources while most wood users can be categorised as obtaining this fuel from formal commercial sources[9].

Table 5. Number and Proportion of Households classified as Formal or Informal Solid Fuel Market Participants

	Sod Peat *N*=285[a]	Wood *N*=704[a]
FORMAL	48 (16.84%)	376 (53.41%)
INFORMAL/GREY	107 (37.54%)	84 (11.93%)
INFORMAL/INDIGENOUS	126 (44.21%)	227 (32.24%)
OTHER/UNSPECIFIED	4 (1.4%)	17 (2.41%)

[a]7 sod peat observations and 30 wood observations are excluded because there did not exist a unique large proportion of solid fuel consumption. That is, across at least two of the sources the largest solid fuel consumption was equal.

Tables 6 and 7 presents results from estimating a multinomial logit model using the unordered categorical variables for sod peat and wood presented in table 5 and the set of location, household and house characteristics previously outlined. The other/unspecified

[9] Other methods to categorise formal and informal solid fuel sources were explored including defining the categories based on whether 50% or more of their solid fuel consumption came from one of the sources. This produced roughly similar proportions and more undeterminable instances however (e.g., 40%, 30%, 30% shares) which is less desirable.

category is excluded in both cases from the analysis given the small number of observations for this source. The estimates are presented as relative risk ratios (RRR) which are calculated as e^{β_j} and can be interpreted as representing the extent to which an outcome changes relative to the reference outcome for a unit change in an explanatory variable (Curtis et al, 2018). With households defined as formal users designated as the reference category, the estimates represent the relative risk of being in either the informal grey or informal indigenous categories for a change in an explanatory variable (or a discrete change from 0 to 1 as the explanatory variables are also categorical). An estimated RRR of greater than 1 indicates an increase in the relative risk while an estimated RRR of less than 1 indicates a decrease in the relative risk. The higher the RRR value above 1 or the lower the RRR value below 1, the greater the magnitude of the increase or decrease in the relative risk.

Looking to the sod peat estimates first, households that use this fuel as their primary space heating option have a very strong positive association with sourcing sod peat informally. The estimated RRR is also relatively larger for informal indigenous sources showing the effect is much greater for those who obtain solid fuels from this source. This highlights the dependence that primary sod peat users have on informal sources relative to formal sources. Cost motivations are also important. Households that consider cost to be an important factor in their decision to use solid fuels have a higher relative risk of sourcing sod peat informally relative to formal sources. In contrast, having a strong knowledge of the health and environmental impact of solid fuels does not play a significant role in this decision.

Location, as expected, is important but particularly for informal indigenous users. Living in the Border and West regions increases the relative risk of sourcing the majority of sod peat from informal indigenous sources versus formal sources. The fact that the Midlands regional category is not significant is perhaps a little surprising as peat bogs are also located there but could be explained by the strong effect for primary sod peat users who are also likely to be located in the Midlands region[10]. There are some urban effects with large city users having a lower relative risk (an RRR less than one) in sourcing the majority of their sod peat from informal indigenous sources. Equally large city and mid-sized town users are less likely to

[10] To substantiate this, a sod peat model with the primary user variable excluded was estimated and produced significant Midland effects. The model with the primary user variable is preferred however on the basis that this variable examines whether dependency on solid fuels increases the likelihood of sourcing fuels from informal sources in a more explicit manner. Additionally, the model fit is significantly improved when this variable is included (LR chi2(2) = 34.16***)

Table 6. Multinomial Logit RRR Estimates, Sod Peat

	Formal Sod Peat Users	Informal (Grey) Sod Peat Users	Informal (Indigenous) Sod Peat Users
	REF		
Location - Region			
Dublin (ref)			
Border		1.183	9.856**
Mid-East		0.816	0.868
Midlands		0.917	1.100
Mid-West		1.215	2.693
South-East		0.000	0.117
South-West		0.824	1.832
West		2.173	5.201*
Location - Rural/Urban			
Rural (Pop <1,500) (ref)			
Sm. Town (Pop 1,500<5,000)		0.680	1.065
Lrg. Town (Pop 5,000<50,000)		0.314*	0.720
City (Pop >50,000)		0.258*	0.139**
Annual Net Household Income			
Under €20,000 (ref)			
€20,000–€30,999		0.659	0.466
€31,000–€49,999		1.942	3.513*
€50,000–€78,999		6.062**	9.100***
€79,000 or over		4.089	6.583**
Age of Oldest Adult			
18–34 years (ref)			
35–54 years		0.573	0.453
55–74 years		0.982	1.055
75 years or over		14.336	9.732
Dwelling Age			
1980 or earlier (ref)			
1981–1990		0.374	0.504
1991–2000		0.511	0.514
2001–2010		0.591	0.744
2011 or later		0.118**	0.689
Primary User			
No (ref)			
Yes		17.264***	47.988***
Cost Motivations for using Solid Fuels			
No (ref)			
Yes		4.939***	4.672***
Knowledge of Impact of Solid Fuels			
No (ref)			
Yes		1.143	1.447
No. Of Observations		281	
LR $\chi 2$ (48)		123.68***	
Pseudo R^2		0.2138	

REF = reference category in multinomial logit model
ref = reference category in categorical variables
***p-value<0.01, **p-value<0.05, * p-value<0.10

source the majority of their sod peat from informal grey sources. Of more relevance is the fact that these results show that large city and mid-sized town users are more likely to source the majority of their sod peat from formal sources, further confirming the belief that a certain amount of sod peat is sourced formally in large urban centres.

Table 7. Multinomial Logit RRR Estimates, Wood

	Formal Wood Users	Informal (Grey) Wood Users	Informal (Indigenous) Wood Users
	REF		
Location - Region			
Dublin (ref)			
Border		0.845	0.754
Mid-East		1.072	1.101
Midlands		1.681	0.805
Mid-West		1.663	0.971
South-East		1.490	0.648
South-West		1.423	0.830
West		1.486	1.103
Location - Rural/Urban			
Rural (Pop <1,500) (ref)			
Sm. Town (Pop 1,500<5,000)		0.807	0.570**
Lrg. Town (Pop 5,000<50,000)		0.485**	0.204***
City (Pop >50,000)		0.469	0.334***
Annual Net Household Income			
Under €20,000 (ref)			
€20,000–€30,999		1.287	1.181
€31,000–€49,999		1.759	1.501
€50,000–€78,999		1.577	1.659*
€79,000 or over		0.830	1.237
Age of Oldest Adult			
18–34 years (ref)			
35–54 years		2.251*	1.218
55–74 years		1.581	1.575
75 years or over		2.813	4.101***
Dwelling Age			
1980 or earlier (ref)			
1981–1990		1.030	0.825
1991–2000		1.955**	1.180
2001–2010		0.669	0.546**
2011 or later		1.199	0.361
Primary User			
No (ref)			
Yes		1.585	1.010
Cost Motivations for using Solid Fuels			
No (ref)			
Yes		1.105	1.498***
Knowledge of Impact of Solid Fuels			
No (ref)			
Yes		1.157	1.804***
No. Of Observations		687	
LR $\chi2$ (48)		115.25***	
Pseudo R^2		0.0880	

REF = reference category in multinomial logit model
ref = reference category in categorical variables
***p-value<0.01, **p-value<0.05, * p-value<0.10

The only other house and household characteristics to display statistical significance is household income. The estimated RRR's are interesting in that they indicate an increased relative risk of sourcing the majority of sod peat informally (particularly indigenous) for those on higher levels of household's income. While there is little research on the effect that income plays on the propensity to obtain solid fuels from grey or indigenous sources, the expectation might have been that lower income families would engage in this behaviour to a greater extent based on the energy ladder theory. The results go against this expectation, however. The positive income effect is especially strong for informal indigenous sod peat users which reinforces the view that a substitution away from traditional solid fuels which are sourced informally does not occur as income increases.

There are less clear statistical differences between formal and informal wood users. One unsurprising exception is the fact that households living in rural areas are more likely to source wood informally. While this location variable plays a clear role, regional location does not. This again is not that surprising given that wood sources (trees, forests, scrub) are equally likely to be present in all regions. Cost motivations once again are significant but only for sourcing informal indigenous wood. This likely reflects the fact that the sourcing of informal indigenous wood is effectively costless. Those who source informal indigenous wood also have better knowledge of the health and environmental impact of solid fuels relative to those who purchase wood from formal sources. It could be case that informal indigenous wood users are more experienced (relative to formal users) in the practice of storing and drying wood to an acceptable level to optimise its heat burning capabilities and in turn, minimise the health and environmental impact. In contrast to the sod peat estimates, there is no statistical difference in the probability of primary and supplementary users sourcing wood formally or informally.

The age of the oldest adult is a significant factor for some age groups. If the oldest adult is aged between 35 and 54, the household has a higher relative risk of obtaining wood from grey sources in contrast to formal sources while if the oldest adult is aged 75 or over, the household has a higher relative risk of obtaining wood from indigenous markets in contrast to formal sources. The latter result provides evidence to refute the suggestion that older age groups are less likely to harvest or forage wood themselves or ask others to do so. There is evidence to suggest that occupants living in dwellings built between 1991-2000 (for grey sources) and 2000-2010 (for indigenous source) have a higher relative risk of engaging in informal wood use. This may be linked to Greener Homes Scheme (GHS) operated by the SEAI between 2006 and 2011, which supported householders who were installing or replacing their heating system to install a renewable energy heating technology, including wood pellet/chip stoves and boilers, although the possibility that a clear link exists between the two would have to be examined further. Finally, household income plays a partial positive role with weak significance for those earning between €50,000 and €78,999 on the relative risk of engaging in informal indigenous sources of wood.

4.3 Policy Preferences of Formal and Informal Solid Fuel users

In addition to location, household and house characteristics, differences between those that predominantly engage in informal solid fuel use versus those that do not can also be examined through differences in their stated policy preferences. Successful implementation of new solid fuel regulations is dependent on having the majority of solid fuel users engage in the regulated formal market. An examination of differences in policy preferences between formal and informal solid fuel users may therefore provide helpful insights. The survey asked all respondents to indicate their support or opposition to several policies designed to reduce the use of solid fuels. These included increasing the carbon tax on the use of solid fuels, introducing a law banning the use of all smoky or introducing regulations covering the quality of solid fuels that can be purchased, grants for retrofitting homes and/or changing heating systems and the introduction of building regulations for new homes which will ban the use of solid fuels for space heating. Table 8 presents test statistics (z values) and their statistical significance for whether informal peat or informal wood users are more likely to state that they support rather than oppose the above policies in comparison to formal peat/wood users.

Table 8. Estimated Z-values[a] from a test of whether informal peat/wood users support rather than oppose policies to reduce the use of solid fuels.

Support for the following policies	Sod Peat (N=281) Grey	Sod Peat (N=281) Indigenous	Wood (N=687) Grey	Wood (N=687) Indigenous
Increasing the carbon tax on the use of solid fuels	-1.49	-2.66***	-1.58	-3.36***
Introducing a law banning the use of all smoky or introducing regulations covering the quality of solid fuels that can be purchased	-3.16***	-2.73***	-1.82*	-3.30***
Grants for retrofitting homes and/or changing heating systems	-0.19	-0.18	-0.15	1.82*
Introduction of building regulations for new homes which will ban the use of solid fuels for space heating	-1.95*	-2.84***	-1.52	-3.87***

***p-value<0.01, **p-value<0.05, * p-value<0.10

[a]Produced from estimating a multinomial logit model using the unordered categorical variables for sod peat and wood presented in table 5 as the dependent variables and a categorial variable indicating support/opposition to the stated policy as a dependent variable.

Almost all of the estimated z-values are negative which indicates that both grey and indigenous peat/wood users are more likely to state that they oppose policies that have the potential to reduce the use of solid fuels in comparison to formal peat/wood users. Statistically, the effects are significant for laws banning the use of solid fuels or regulations covering their quality. The effects are also noticeably more statistically significant (i.e. at the 1% level of significance) for indigenous users further highlighting the importance they place on continuing the use of solid fuels. From a statistical point of view, grants for retrofitting homes and/or changing heating systems are equally supported/opposed by formal and informal solid fuel users. Moreover, this policy is found to be more supported by indigenous wood users than formal wood users based on the positive and significant (at a 10% level) test statistic. It is perhaps not surprising to find that financial incentives are more favoured relative to policies which restrict the use of solid fuels.

4.4 Discussion

Of the limited previous research in this area, only the role of location had an element of certainty about it. The results presented above further highlights the importance that it plays in how households source sod peat and wood. Not surprisingly, an urban/rural effect is present, although not strictly based on a division by urban and rural areas. Larger urban centres (above 5,000 population) are more likely to source solid fuels formally, but smaller urban centres and rural areas are statistically equally likely to source solid fuels formally and informally. A consequence of this is that while new solid fuel regulations which propose to cover formal sources, will likely be effective in targeting emissions of particulate matter in larger urban centres. But if solid fuel use from informal sources remains unregulated, this may have implications for air quality in smaller urban centres in particular. A strong regional effect is also present for informally sourced sod peat. As previously suggested, ease of access to informal sources could be an obstacle for policy makers in encouraging a transition away from the use of solid fuels with potentially poor environmental and health standards. Such a finding supports previous research by Fu et al. (2014) who calculated an index measuring the resistance to change from using solid fuels and found high values in areas where bogs were located, although their analysis covered solid fuels as a whole and did not distinguish between formally and informally sourced solid fuels in contrast to this study.

The research has advanced the understanding surrounding the effects of other variables, besides location. Cost motivations are also an important factor for increasing the likelihood of using informal sources of solid fuels. This is shown in the multinomial logit results but also in the stated opposition that informal solid fuel users have for increases in the carbon tax. In tandem with the introduction of new solid fuel regulations, there is a commitment to increase the carbon tax on an incremental basis to €100 a tonne by 2030, which will have an effect of increasing the price of commercial solid fuels. Therefore, with the introduction of new environmental standards and higher prices, and cost as a strong motivator for sourcing fuels informally, the potential for switching to occur to unregulated fuels from this source may be an unexpected consequence. This can occur, not only with price increases due to tax measures but also where global energy prices increase, given Ireland’s exposure to global energy markets. This is clearly an issue that policy makers will need to monitor carefully.

The fact that some solid fuel users, especially sod peat users, are dependent on informal sources as their primary means of space heating their home is another important message for policy makers. This suggests another strong barrier to any policy that supports a transition to formal sources of fuels whether that be sod peat or other solid fuels. This is reiterated by the stated opposition to policies as shown in table 8 which propose banning or regulating the use of solid fuels. The positive and significant income effects (especially in the sod peat model) also have interesting policy implications. These findings underline the important point that there is a difference between income poor and fuel poor. It is evident from the results that informal solid fuels users are fuel poor rather than income poor, in that they do not have alternative fuels to use if informal fuel sources are restricted in some way (especially for sod peat users). Policies could therefore focus on providing more cost-effective fuel alternatives and/or incentives to change heating systems rather than measures which simply compensate these households in a financial way e.g. a fuel allowance. The fact that there is stated support for grants for retrofitting homes and/or changing heating systems, even among informal solid fuel users, shows that providing alternative space heating options could encourage solid fuel users to reduce or eliminate consumption.

5. Conclusion and Policy Implications

This paper provides an analysis of the informal solid fuel sector in Ireland, where informal is taken to mean instances where households obtain solid fuels through grey sources or when solid fuels have been harvested or foraged on one's own land. While some analysis of informal fuel use has been carried out for developing countries, limited detailed research has been carried out for developed countries. This is despite the fact that in some countries, such as Ireland, solid fuels still comprise a significant amount of the fuel used for space heating purposes and sourcing these fuels outside of formal commercial channels is common. The paper had two main objectives, to quantify the extent to which solid fuels are sourced informally in Ireland and to examine the characteristics of those households that predominately source solid fuels informally versus those that do not, to identify any features that may be useful to policy makers. The paper focuses on sod peat and wood as these two solid fuels are ones which are more likely to be informally sourced.

The analysis was carried out using a detailed online survey of solid fuel users. A comprehensive methodology in comparison to previous surveys of informal solid fuel use was applied which aimed to capture the extent to which households source their solid fuels from a wide range of possibilities. In contrast to previous research, the sources were categorised into formal and two informal sources, grey and indigenous, on the basis that these were two distinct subsets of the informal solid fuels sector. The majority of sod peat is estimated to be informally sourced with a larger proportion of this based on indigenous sources than grey sources. It is the first time an attempt has been made at approximating the extent to which sod peat is sourced informally. Informal wood use is estimated to comprise approximately half of overall wood use. This estimate is considerably higher that estimates previously made by the SEAI and therefore provides an update on their current knowledge. The underestimation of the extent of informal wood use may also have implications for estimates of overall wood use produced by the SEAI.

Significant characteristics of those defined as formal or informal solid fuel users were identified and showed that location, having strong cost motivations for using solid fuels, being a primary user of solid fuels and being on higher levels of household income all increased the relative risk of sourcing solid fuels informally. Moreover, these factors were more likely to identify an informal sod peat user and particularly one who obtains the fuel from indigenous sources. An analysis of policy preferences also highlighted significant differences between formal and informal solid fuel users, with informal users opposing restrictions on the use of solid fuels but favouring grants to retrofit homes and/or change heating systems. This highlights the difficulties that policymakers face in incentivising informal solid fuel users to eliminate consumption as householders that retrofit homes and/or change heating systems may still desire the use solid fuels as a backup fuel source.

A number of recommendations can be given arising from the research presented in this paper. These can be directed at statistical agencies that gather and interpret residential energy data as well as policy makers who are designing incentives to transition households away from using unregulated environmentally damaging solid fuels. For statistical agencies:

- The analysis in this paper suggests that informal wood use may have been underestimated in previous attempts, with possible implications for how overall wood energy use in the residential sector is measured. More evidence and data gathering by statistical agencies is required to investigate this further. Verifying the extent of formally and informally sourced sod peat would also bring further clarity to this ‘data gap’.
- The methodological approach to measure the extent of the informal solid fuel sector can easily be adapted and used in future surveys providing the means by which this important area can be monitored. Accounting for the wide range of ways in which solid fuels can be sourced informally and distinguishing between grey and indigenous informal sources are two key contributions that future statistical work in this area should be cognisant of.
- While the number of observations for sod peat and wood users in the survey were of a reasonable size, any future survey of the extent of formal and informal solid fuel use would be enhanced if the sample sizes were increased. One benefit of this would be to provide greater certainty when scaling up the figures to national estimates. Thus, a limited version of the survey but to a broader sample is recommended, bearing in mind the difficulty and costs associated with reaching some of the target audience i.e. isolated rural areas.
- A future survey would also be improved if more detailed information on fuel consumption and energy use data was collected. The approach taken in the survey in this paper was to estimate daily consumption using a volume measure (based on a standard sized receptacle). Other approaches could be trialled including complementing daily estimated values with long-term estimates based on a bulk delivery or harvest. The ease to which quantity data can be converted into energy use data (e.g. kilo tonnes of oil equivalent, ktoe) is another important consideration, given that the SEAI produce

statistics on final energy consumption data for the residential sector for each fuel in ktoe terms.

- Finally, while the focus of the study has been on Ireland, the literature review has shown that similar issues are pertinent to other developed countries, including the UK and many Nordic countries, and thus the recommendations given can also be helpful to statistical agencies in these countries, who may be grappling with ways in which to accurately measures the extent of both formal and informal solid fuel use.

The research can also be of benefit to policy makers, particularly in considering the effectiveness of solid fuel regulations which are being introduced in Ireland at the present time.

- It is likely that new solid fuel regulations will be effective in reducing particulate emissions in large urban centres where formal or commercial purchases of solid fuels are made. There may be less certainty regarding the effectiveness in smaller urban centres where informal sources of solid fuels are more common.
- Furthermore, given that the new regulations will cover formal purchases of solid fuels, an environmental standards disparity with the use of informally sourced solid fuels would be created. The potential for substitution to the solid fuel alternatives obtained through these channels will have to be carefully monitored for effective implementation of new and existing solid fuel policies.
- Thus, in addition to the benefits to statistical agencies, a survey of formal and informal solid fuel use, carried out on a periodic basis would also provide a baseline against which progress in relation to policies implemented could be measured and tracked.
- To reduce the potential for substitution to unregulated informally sourced solid fuels and ultimately support a transition toward less environmentally damaging regulated commercial solid fuels, policy makers need to consider the importance that cost motivations can play and ensure any price disparities between regulated and unregulated solid fuels are addressed by, for example, reducing VAT on regulated solid fuels.

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