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The Cost of Natural Gas Shortages in Ireland

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Abstract: This paper investigates the economic implications of disruptions of one to ninety days to the supply of natural gas in Ireland. We assess the impact of a hypothetical gas supply disruption in both winter and summer in 2008 (with observed market characteristics) and in 2020 (with projected market characteristics). The cost of a natural gas outage includes the cost of natural gas being unavailable for heating and other purposes in the industrial and commercial sectors, lost consumer surplus in the residential sector, the cost of lost electricity in all sectors and lost VAT on the sale of gas and electricity. Ireland produces much of its electricity from natural gas and the loss of this electricity accounts for the majority of the cost of a natural gas outage. Losing gas-fired electricity would cost 0.1 to 1.0 billion euro per day, depending on the time of week, the time of year, and rationing of electricity. Industry should be rationed before households to minimize economic losses, but current emergency protocols favour industry. If gas-fired electricity is unavailable for three months, the economic loss could be up to 80 billion euro, about half of Gross Domestic Product. Losing gas for heating too would add up to approximately 8 billion euro in economic losses. We also discuss some options to increase Ireland's security of supply, and find that the cost is a small fraction of the avoided maximum damage.

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Key words: Security of supply; natural gas, value of lost load, Ireland

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1. Introduction

Energy security is back in vogue. Concerns about rapid demand growth, resource scarcity, concentration of reserves in unstable or hostile hands, and adverse weather have reminded people that the supply of energy is not guaranteed. Such worries are often qualitative, sometimes even speculative. In this paper, we attempt to quantify the cost of a gas outage. What economic damage would be done if Ireland were without gas? The answer to that question is of obvious interest to people who are considering investing in improving Ireland's gas security. However, the order of magnitude (large) and the method (replicable) should be of wider interest.

Ninety-two percent of Ireland's gas supply was imported in 2008 (SEAI, 2009). Any disruptions to the international flow of gas would have a significant impact on the economy. In this paper, we investigate what the cost and possible implications of such a disruption might be for the Republic of Ireland. Without speculating on the possible causes or the probabilities, we quantify the economic losses associated with being without gas for one day, three weeks and three months. We separately analyse the costs associated with the electricity shortages that would arise if the supply of natural gas were disrupted. We find that the disruption to the electricity supply which occurs as a result of a gas outage accounts for, on average, 86% of the total cost of a natural gas disruption in Ireland. We also compare the costs associated with three alternative electricity rationing policies. The results indicate that large savings can be made if the industrial sector is preferentially rationed. Preferentially rationing the residential sector is always most expensive. To our knowledge, this is the first and only empirical estimate of the value of natural gas shortages in Ireland.

The number of natural gas customers in Ireland is increasing, especially in the residential sector. Increased availability and the reputation of gas as the cleanest fossil fuel have assisted this increase. Included in the total cost of a natural gas outage is the loss of consumer surplus for the buyers of gas in the residential sector and the loss of producer surplus for the suppliers of gas to the residential sector. We quantify the loss of both consumer and producer surplus over different time periods and we discuss the impact on households if gas were not available for heating and cooking.

Two EU directives, one concerning measures to safeguard security of electricity supply and infrastructure development was passed in 2006[1] and the other, passed in 2004, is concerned with measures to safeguard security of natural gas supply.[2] This, along with recent Russia-Ukraine gas disputes, has placed security of supply high on the agenda of

[1] Directive 2005/89/EC (EU, 2006)
[2] Directive 2004/67/EC (EU, 2004)

many European countries. Security of supply can be defined as "an uninterrupted flow of energy to meet demand in an environmental sustainable manner and at a price level that does not disrupt the course of the economy" (Damigos et al., 2009). Given that Ireland's gas demand is increasing and that Ireland is hugely dependent on natural gas imports, it is important to consider what the implications of a natural gas shortage might be.

Security of the natural gas supply has received some attention in Ireland to date. In 1999 Bord Gáis[3] examined ways in which Ireland can meet increased future gas demand. In 2009, the Commission for Energy Regulation in Ireland (CER) published a report which looked at the security of supply issue as well as the quality of gas being imported into Ireland. Neither study considered the economic impact of possible gas supply shortages, however. To our knowledge, this is the first estimate of the cost of disruptions to the natural gas supply on the island of Ireland.

This topic has been studied in other countries. Damigos et al. (2009) used consumer surveys to estimate Greek households' willingness to pay for safeguarding security of natural gas supply in electricity generation. The results of this study, which was conducted using the contingent valuation method, indicate that on average consumers are willing to pay a premium of 7% of their annual electricity bill in order to ensure the supply of gas. We are unable to conduct such a study since no Irish data of this kind exists.

In 2006 Ilex Energy Consulting, on behalf of the Department of Trade and Investment in the UK (DTI), published a report which investigated the economic implications of a gas supply interruption to UK energy intensive industry in the winter of 2005/06. The effect of the disruption on sectors upstream and downstream of energy intensive industries was also considered but the cost of an outage to the residential sector is not measured. Using a combination of interviews which were carried out with companies and trade organisations in the UK, as well as data published by the ONS, the report considers shortages lasting 1 day, 3 weeks and 6 weeks. A disruption to industry lasting 6 weeks could cost £2.3 billion (0.18% of annual Gross Domestic Product (GDP) in 2006)[4], assuming that almost all of the energy intensive sectors cease production but that the sectors directly upstream and downstream are unaffected. In such a scenario it is assumed that alternative suppliers/customers for all purchases/sales can be found at no extra cost. However, the disruption could cost over £10.5 billion (0.81% of annual GDP in 2006) if upstream and downstream sectors are also forced to cease production. Due to data limitations, we do not consider the cost of lost production or sales in upstream and downstream sectors.

In 2007, Oxera prepared a report for DTI in which the cost of expected forced gas shortages between 2007/08 and 2020/21 was estimated for the UK. It was assumed that the loss is

[3] Bord Gáis, established in 1976, is a commercial State body operating in the energy industry. It currently has over 630,000 gas and electricity customers (Bord Gáis, 2010a).

[4] UK GDP in 2006 was £1.3 trillion (ONS, 2008).

equal to the gross value added (GVA) foregone. The findings show that forced shortages in 2020/21 could cost £612 million (or a net present value of £1.26 billion if discounted at 3.5%). The NPV would be about 0.08% of UK GDP in 2020 as forecast by Goldman Sachs (2003). As the residential sector does not contribute to GVA, the cost of gas shortages to households is not included.

The paper continues as follows. Section 2 describes the data and methods used. The results are presented in section 3. We discuss the implications of natural gas shortages in Ireland in section 4. Section 5 concludes.

2. Data and Methods

2.1 Gas in electricity production

In 2008, over 23% of Ireland's primary energy demand was met using natural gas and almost 55% of Ireland's electricity was produced using natural gas (SEAI, 2009). Thus, it is important to assess the effect of a natural gas shortage on electricity availability. The ESRI's electricity generation model IDEM (ESRI, 2010) is used to estimate the number and magnitude of blackouts in Ireland in the event of natural gas being unavailable for electricity generation in 2008 and 2020. IDEM is a model of the dispatch of electricity. For every half hour, it balances supply and demand using a merit order curve, adjusted for priority dispatch, feed-in tariffs, carbon price, maintenance, and other relevant factors. As the Irish power system is relatively small, all power plants are separately represented.[5]

For 2008, IDEM uses the observed half hourly electricity demand profile in ROI and NI reported by Eirgrid (2009a). The model forecasts the half hourly demand profile for 2020. The daily demand profiles for each year can be seen in appendix 1. For the purpose of this paper, IDEM is run so that that all gas-fuelled plants in both the Republic of Ireland (ROI) and Northern Ireland (NI) are inactive. To account for likely coincident gas shortages in Great Britain, we assume that no power will be imported through interconnection. This means that the Irish system can rely only on coal, peat, oil, wind and the small amounts of other renewables on the system. For both years, two scenarios are considered. In the first, Moneypoint[6] operates at its 2008 availability,[7] and in the second, it is assumed that all scheduled maintenance work at Moneypoint is postponed and it operates at full availability.[8] For 2020, two further scenarios are considered: one assumes that installed

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5 Ireland and Great Britain are interconnected, but this is irrelevant for the current analysis.

6 Moneypoint, a coal-fired power plant, is Ireland's largest electricity generating station. It is part of ESB Power Generation Business Unit. The total output capacity of 915MW is delivered by three 305MW steam-generating boiler plants.

7 In 2008, one plant operated on 318 days of the year, the second operated on 219 days and the third operated on 338 days. This represents 875 out of a possible 1095 days, approximately 80%.

8 Full availability assumes that all 3 plants operate on 365 days a year.

wind capacity equals 2000 megawatts (MW), the other 6000 MW. In 2008 installed wind capacity was just over 1000 MW. For all scenarios, the observed 2008 wind profile reported by EirGrid (2009b) is assumed. We also assume that demand does not change in response to the electricity shortage.

First we estimate the size of the electricity shortage on both a midweek and weekend day in January and July in 2008 and 2020. We also estimate the shortfall caused by 3 week and 3 month gas supply disruptions in summer and winter in both years. In a situation where electricity supply cannot meet demand, the rationing of electricity could take different forms. We consider what the implications of these options might be. First, each sector could lose electricity in proportion to its share of overall electricity consumption. We call this proportional rationing. Second, electricity could be preferentially rationed in the sector with the lowest gross value added per unit of electricity (industry), or, in the worst case scenario, electricity would be preferentially rationed in the sector with the highest value added per unit of electricity (residential).

We assume that the shortfall will affect ROI and NI in proportion to the amount of electricity used in each jurisdiction. In order to quantify the cost of electricity shortfalls we multiply the shortage in kilowatt hours (kWh) by the value of a unit of electricity. This value differs by sector and between ROI and NI. We find the value of one kWh of electricity, also known as the Value of lost load (VoLL), in the industrial, commercial and residential sectors in 2008 and 2020. As in Tol (2007) and Leahy and Tol (2010), the VoLL can be determined by dividing the annual Gross Value Added (GVA) per sector by the amount of electricity used by that sector. In the case of households, we cannot measure GVA but we do value the time spent at non paid work. As in de Nooij et al. (2007), Tol (2007) and Leahy and Tol (2010), we assume that the value of time spent at non paid work is equal to half of the average wage after tax. Following Leahy and Tol (2010), we incorporate the Time Use in Ireland Survey (ESRI, 2005) in order to determine how people allocate time. We use the 2005 time use profile as a proxy for time use in 2008 and in 2020. For those who are not at home or at home and asleep, the cost of the electricity shortage is 0. For those who are working from home at any particular time, the cost of the electricity shortage is assumed equal to the average wage after tax. For all others, the value of time spent at non paid work is set equal to half of the average wage after tax.

ESB (2009) provided the 2001 electricity use profile for the industrial, commercial and residential sectors in ROI. Taking annual electricity use per sector in 2008 from SEAI's Energy Statistics Report (Howley and Ó Gallachóir, 2009a) and forecasted demand in each sector in 2020 from the ESRI's Sustainable Development Model for Ireland (ISus)[9] we impute the 2008 and 2020 profiles based on the 2001 profile. GVA per sector for ROI in 2008 and 2020 is

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[9] ISus uses both economic and environmental data to forecast energy use, emissions to air and waste out to 2025.

taken from the ESRI databank (Bergin and FitzGerald, 2009). We calculate the value of time spent at non paid work using data on non agricultural wages after tax, also taken from the ESRI databank. We estimate VoLL per sector for NI in 2008 following the method of Leahy and Tol (2010). In order to calculate the VoLL per sector in NI in 2020 we assume the same growth pattern as ROI because published forecasts of GVA and electricity use for NI are not available.

2.2 Consumer Surplus

We estimate the cost of a gas outage in the residential sector in terms of consumer surplus. Gas represents over a fifth of all fuels used in the residential sector in ROI (SEAI, 2009). Its main functions are space heating, water heating and cooking. Previously natural gas was only available in the cities of Dublin, Cork, Limerick and Galway. It is now becoming more widely available in smaller towns. Bord Gáis, the state-owned supplier in ROI, has only one competitor in the residential sector: Flogas, which went nationwide in 2009. The 2004/05 Household Budget Survey (CSO, 2008) allows us to analyse the characteristics of residential users of natural gas in ROI. A typical user is an urban dweller, is relatively well educated and earns a relatively high income. A more detailed account of gas users' characteristics can be seen in appendix 2. In NI, gas is supplied to the residential sector by Phoenix and since 2005 by Firmus Energy, a subsidiary of Bord Gáis.

The value of a natural gas disruption to households is equal to the consumer surplus that would be lost if natural gas were unavailable for heating and cooking. Consumer surplus is the difference between the price consumers are willing to pay for a good or service and the price they actually pay. Thus, it is used as a measure of welfare that people derive from consumption of goods or services. Here we assume that all gas is lost and, as a result, consumer surplus falls to zero. We estimate the loss in consumer surplus for 1 day, 3 weeks and 3 months in 2008 and in 2020. Using data provided by Bord Gáis Networks (2009), we know the amount of gas that was demanded in the residential sector in ROI on each day of 2008.[10] Northern Ireland's Utility Regulator (URegNI) (2010) provides data on annual Gas demand in the residential sector in NI and we assume that the daily profile follows that of ROI. Many studies including Baker and Blundell (1991) and Berkhout et al. (2004) find that the elasticity of demand for gas in the residential sector is inelastic. We use an elasticity of -0.16, estimated by Asche, Nilsen and Tveterås (2008). We also carry out a sensitivity analysis in which we decrease the elasticity to -0.5 as this is the elasticity estimated for UK households (Baker and Blundell, 1991). We also increase the elasticity to -.01. An elasticity

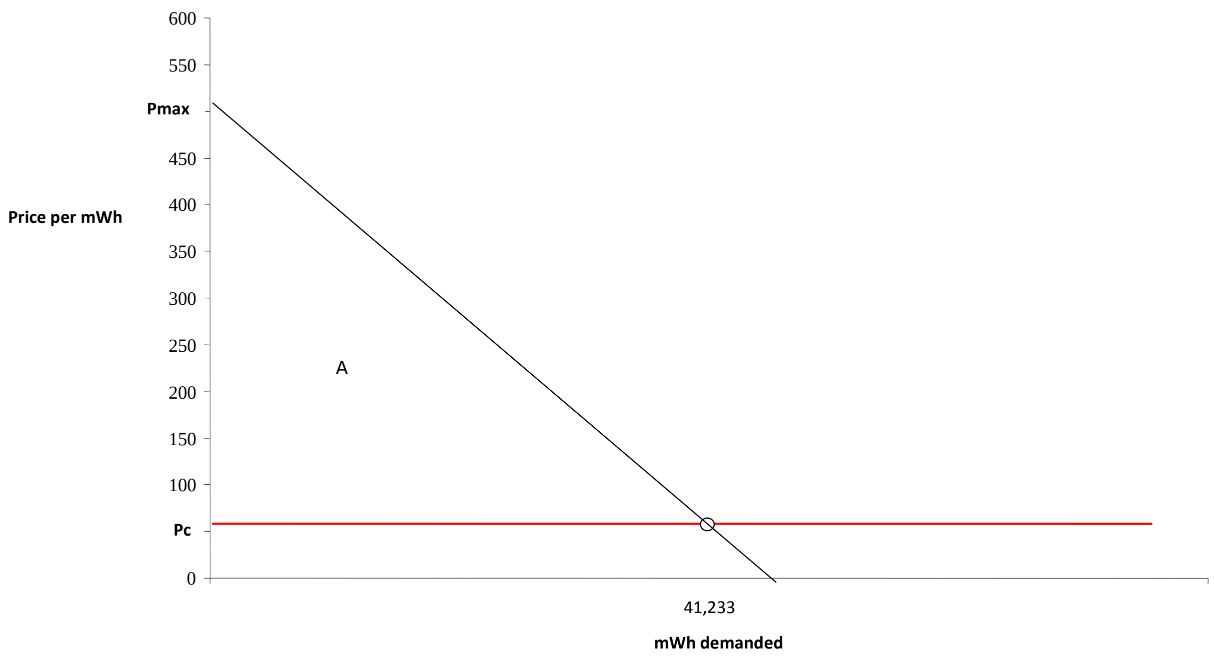
[10] The data are for the entire non daily metered (NDM) sector; however, Bord Gáis (2010b) provides estimates of the proportion of the NDM gas demand which is attributed to households at different times of year.

greater than zero would indicate that the demand for natural gas is elastic, which we do not believe to be the case.

In order to estimate consumer surplus we need to know the price at which gas is sold to the residential sector. Howley and Ó Gallachóir (2009a) provide details of 2008 prices. For 2020 we assume that prices increase by 5% as was assumed by Howley and Ó Gallachóir (2009b). ISus forecasts annual residential gas demand in 2020 for ROI. Again, we assume that the growth in demand in NI is the same as that of ROI. For both ROI and NI, we assume that the 2020 profile follows that of 2008. This is realistic since the most important determinant of gas demand is weather (Diffney et al., 2009).

Using the elasticity, the price of gas and the amount of gas that was demanded on a certain day/week/month, we can estimate the slope of the gas demand curve for each relevant period. Figure 1 shows the consumer surplus that was derived when the market operated without interruption on Wednesday, 16th January 2008. Here, an elasticity of -0.16 is assumed. The maximum amount that people are willing to pay is the point at which the demand curve intersects the X axis, (labelled P_{max} in figure 1). P_c is the current price or the price per mWh that residential customers paid on that day. The area labelled "A" is the consumer surplus that is derived. In the case of a gas outage, we assume that the entire consumer surplus is lost.

Figure 1. Consumer Surplus



2.3 Producer Surplus

In the case of a natural gas disruption, the local suppliers of gas will also incur a cost. For those who supply gas to the residential sector, the cost is the loss of producer surplus.

Producer surplus is the difference between the revenue received and the costs of production, i.e. the retail price multiplied by the amount of gas sold for a particular time period minus the wholesale price. The wholesale price is about 58% of the retail price (CER, 2009).

2.4. Reduction in Government revenue

In 2008, residential users of electricity and natural gas paid VAT at a rate of 13.5% of the retail price per unit. For the purposes of this paper we assume the same VAT rate will apply in 2020. Thus, government revenue will be negatively affected if the supply of electricity and natural gas is disrupted. The fall in revenue will depend on the time of year at which the outage occurs and its duration. The amount of VAT lost as a result of an electricity outage will depend on the amount of electricity generated at Moneypoint and on the amount of wind capacity installed.

We estimate the loss in VAT revenue by estimating the shortfall in the supply of gas and electricity and we multiply this by 13.5% of the unit price.

We do not include the VAT that is paid on the sale of electricity and gas to residential customers in Northern Ireland as this loss in revenue is not borne by the Irish government. Industrial and Commercial enterprises in the Republic of Ireland do not pay any VAT on purchases of electricity or natural gas.

2.5. Cost of natural gas and electricity outages combined

For households, the total cost is the loss of consumer surplus plus the cost of the electricity shortfall as explained earlier. For the suppliers of gas to the residential sector, the cost is the loss of producer surplus. Government bear the cost of losing VAT revenue.

For the industrial and commercial sectors we cannot estimate consumer surplus and producer surplus. Instead we estimate the cost of the combined gas and electricity outage as being equal to GVA per sector divided by annual electricity and gas demand, respectively, per sector.[11] We multiply this term by the combined amount of natural gas and electricity which is lost in each sector for each relevant time period.[12]

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[11] This is similar to estimating the VoLL for these sectors except the term now includes both gas and electricity demand for each sector.

[12] The total cost to the industrial and commercial sectors includes the cost incurred by the suppliers of gas to these sectors.

We use the same electricity and GVA data as before. Bord Gáis Networks (2009) provides daily gas demand data for the Industrial and Commercial (non power) sectors in 2008. Forecasted gas demand for these sectors in 2020 is taken from ISus. Gas demand data for NI in 2008 is taken URegNI (2010) and we impute 2020 demand by assuming it increases in line with gas demand in ROI. Again, the profile for both ROI and NI in 2020 is assumed to follow that of 2008.

The results are presented in the next section.

3. Results

3.1. The cost of electricity outages

First we discuss the cost of one day electricity shortages,[13] for which the full results (displayed as cost per person) can be found in appendix 3. The cost of an outage varies by time of week and year and by the type of electricity rationing that is pursued. Using 2008 data, the cost of a 1 day disruption could reach almost €840 million or 0.45% of that year's GVA if electricity is rationed in the residential sector first. One might expect that the cost of a one day shortage should not exceed 1/365th of annual GVA. However, the cost of the disruption places a value on the loss to the residential sector whereas GVA only considers output in the industrial and commercial sectors. The cost falls to 0.1% of annual GVA if electricity is rationed in the industrial sector first because the VoLL is lowest in this sector.[14] One day shortages are seen to cost more in winter than summer in both 2008 and in 2020. In the winter of 2020, the cost of a 1 day shortage could reach over €1.6 billion (0.6%) of that year's GVA if electricity is rationed in the residential sector first.

In 2008 Moneypoint operated 80% of the time. We refer to this as partial availability. We also estimate what the cost of lost electricity would have been if all 3 plants in Moneypoint operated on all days of the year. Because demand for electricity varies between midweek and weekend days, and at different times of year, we show how the cost of the shortage varies with fluctuations in weather and demand.

Figure 2 shows the estimated cost of lost electricity caused by a 1 day gas supply shortage in 2008. The proportional rationing bar indicates the cost of the shortage when each sector in both ROI and NI loses electricity in proportion to the amount it demands. The cost does not vary by partial or full Moneypoint availability in winter, however, some differences are observed in summer. If proportional rationing is used, the cost is highest on midweek days in January when demand in all three sectors (industrial, commercial and residential) is likely to be high. The cost of the shortage is also relatively high on midweek days in July when Moneypoint operates at partial availability. Although demand for electricity is lower at this

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13 Wednesday is taken to be the representative midweek day while Saturday is taken to be the weekend day.

14 In 2008 in ROI, the VoLL for the industrial sector is €4/kWh, for the commercial sector is €14/kWh and, for the residential sector, the average VoLL is €24.57/kWh

time of year, the amount of electricity that tends to be generated by wind turbines is also lower. If electricity is rationed in the residential sector first, the cost is highest on weekend days in winter. This is because the VoLL for households is higher on weekend than midweek days.[15] In each case, the cost of the shortage is highest if electricity is rationed in the sector with the highest VoLL (residential) and lowest when electricity is rationed in the sector with the lowest VoLL (industry).

Figure 2. Cost of 1 day electricity shortage in 2008

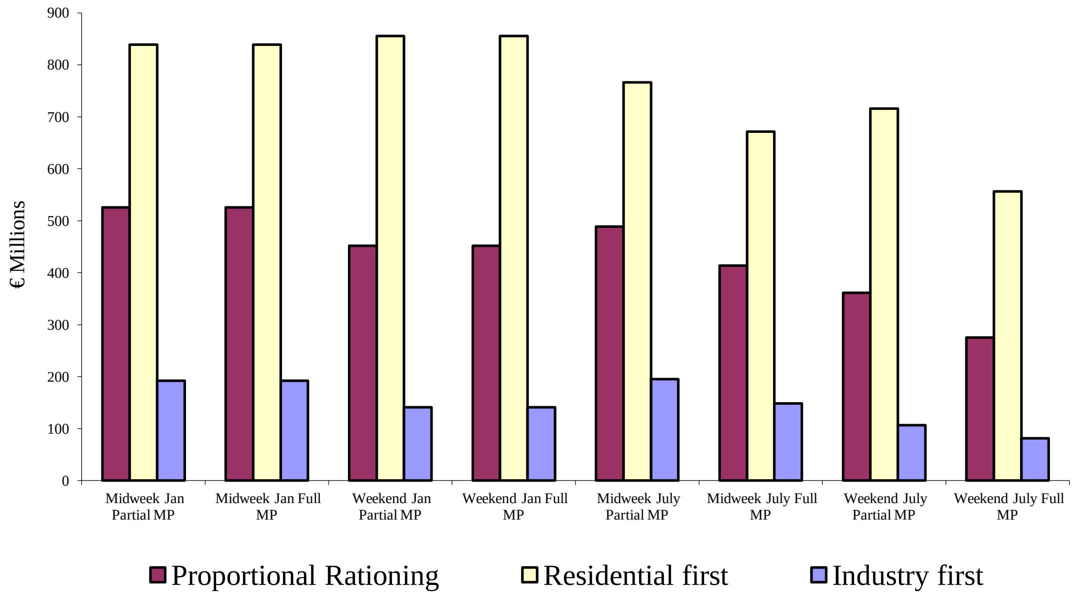

Figure 3 shows the estimated cost of a 1 day electricity shortage in winter 2020. As was the case in 2008, full Moneypoint availability has no effect on the cost of the shortage. For 2020, two scenarios are considered. In the first only 2000 MW of wind are installed while in the second, wind capacity is increased to 6000 MW. Figure 3 shows that the main differences in cost can be attributed to the amount of wind capacity that will be installed. Appendix 3 indicates that on weekdays, about 28% more demand is met if 6000 MW of wind are installed. At weekends, having 6000 MW of wind means 57% of demand can be met whereas only 42% will be met with 2000 MW of wind. The increased wind capacity reduces the cost of the blackout by 28% on weekdays and 36% on weekends. As was the case in 2008, the cost is highest on weekend days if households are rationed first whereas with proportional rationing, the cost is highest on midweek days.

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[15] The VoLL for households is the value of time spent at non paid work divided by electricity use. It is higher at weekends because fewer people are engaged in paid work. A higher value is placed on a unit of domestic electricity when people are at home pursuing leisure and other activities.

Figure 3. Cost of 1 day electricity shortage in winter 2020

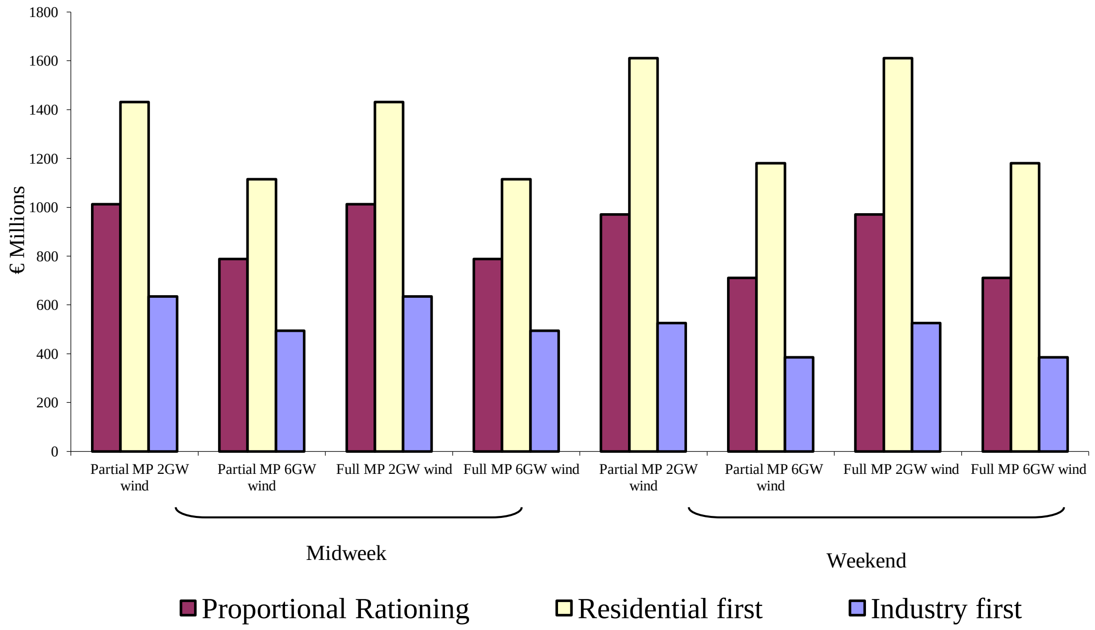
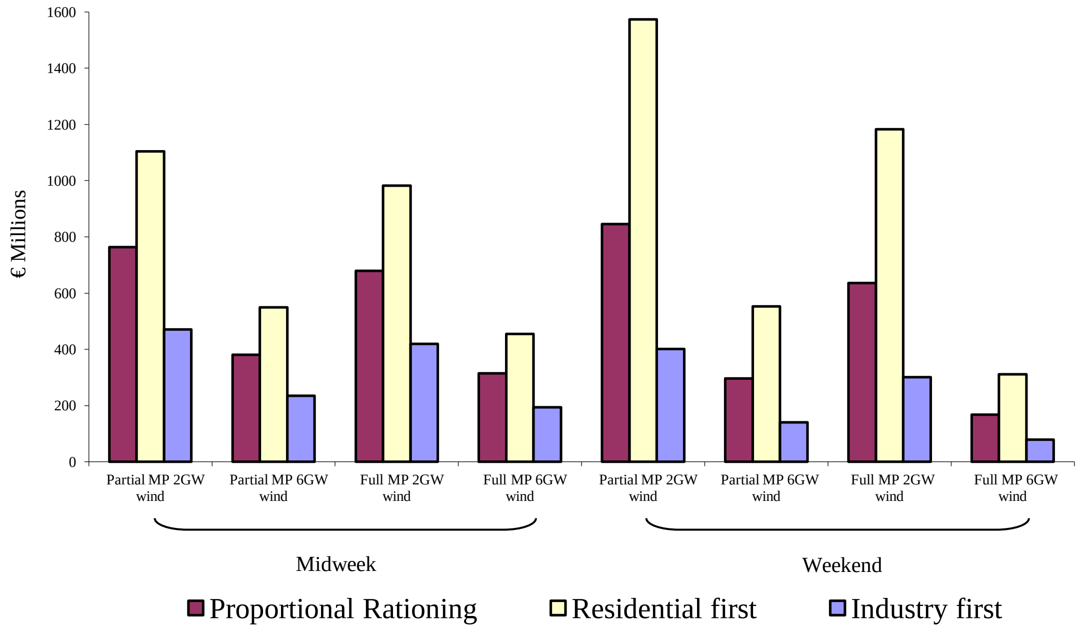


Figure 4 displays the estimated cost of a 1 day electricity shortage on summer days in 2020. In this case, full Moneypoint availability plays a role in reducing the cost of the shortage. However, the main differences in cost are brought about by the amount of wind capacity. On a midweek day with partial Moneypoint availability, the cost of the shortage with 2000 MW of wind are double that of the 6000 MW wind scenario. With full Moneypoint availability, the difference in costs between the low and high wind scenarios is slightly higher. At weekends, even greater cost differences are observed. With partial Moneypoint availability, the cost of the shortage with low wind is almost twice that of high wind and with full Moneypoint availability, the cost of the shortage with low wind is about 3 times higher than it would be with 6000 MW of wind installed. Rationing the residential sector first is always more costly than other types of rationing, especially on weekend days with the low wind scenario. This happens because the average Voll for households on weekend days in July is €31/kWh whereas on midweek days it is only €20/kWh.

Figure 4. Cost of 1 day electricity shortage in summer 2020



We also consider shortages lasting 3 weeks and 3 months of which detailed results (displayed as cost per person) are outlined in appendix 4. Figure 5 shows the estimated cost of a 3 week and 3 month electricity shortage in 2008. First, we compare the cost of a shortage beginning on 7th January 2008 for 3 weeks with one beginning on the 7th of July. Although demand is higher in the winter period, the amount of electricity that was generated by wind was relatively low in July 2008 and so, the cost of the shortage is somewhat similar across periods. If electricity is rationed in the residential sector, the cost of the shortage varies between €16 and €19 million (9-10% of GVA) in both periods. If proportional rationing is used the cost is only about 5% of annual GVA (or almost €10 million). The cost falls substantially if electricity is rationed in the industrial sector first.

We also compare the costs of an outage lasting for 3 months in winter (December, January, February) and summer (June, July, August). For a 3 month outage, the differences between costs of winter and summer outages are small. This is probably due to the fact that not all of the wind capacity that was on the system could be exploited in summer of 2008, even though demand was substantially lower in summer than winter. Again, the cost of a shortage varies dramatically depending on the type of rationing pursued.

Figure 5. Cost of 3 week and 3 month electricity shortages in 2008

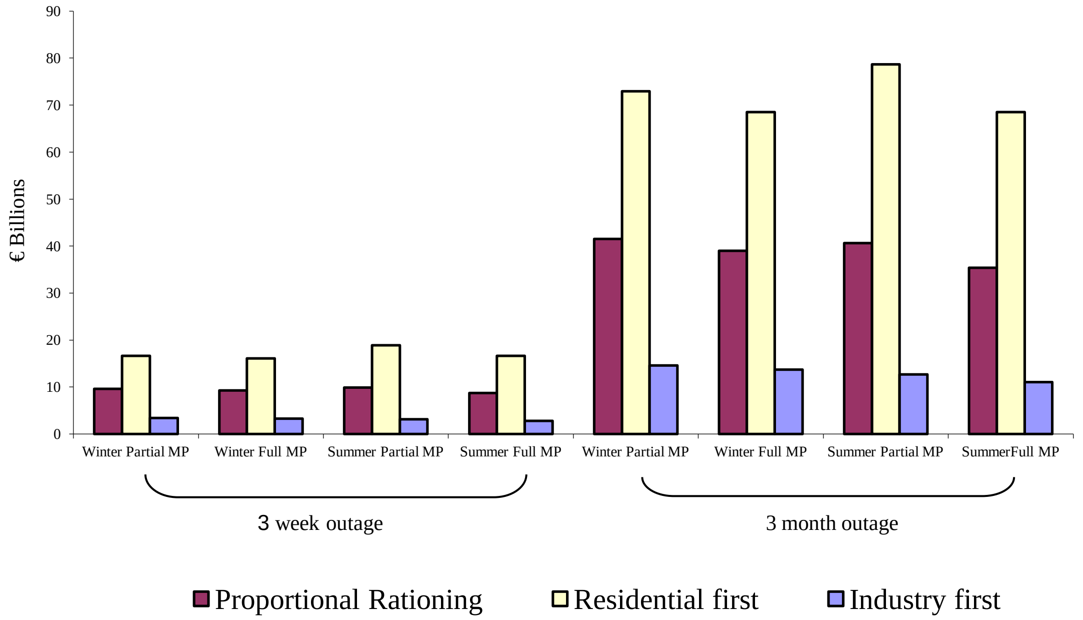
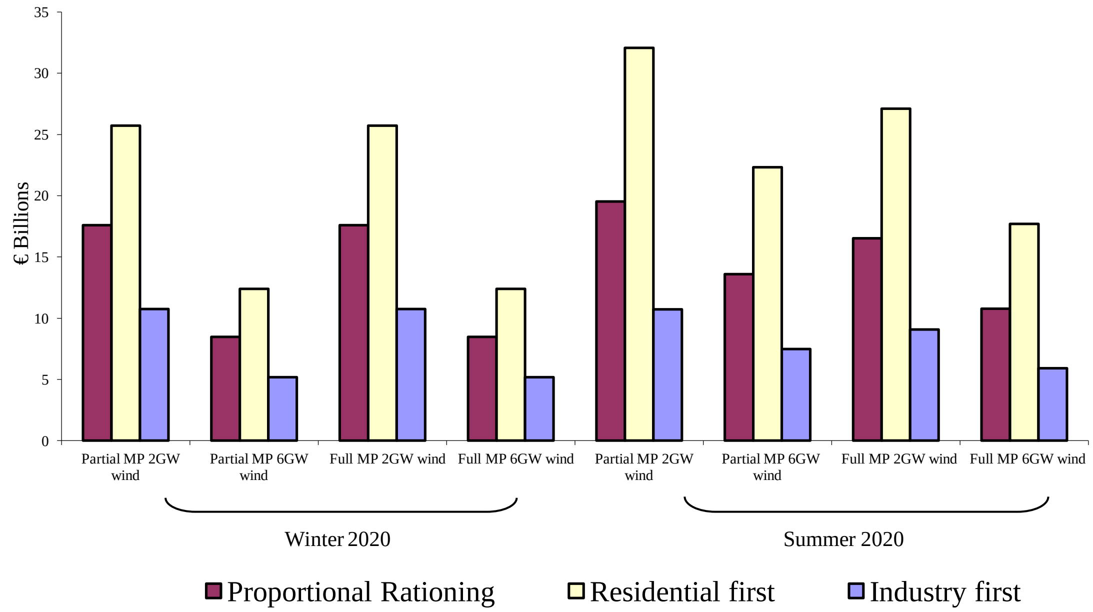


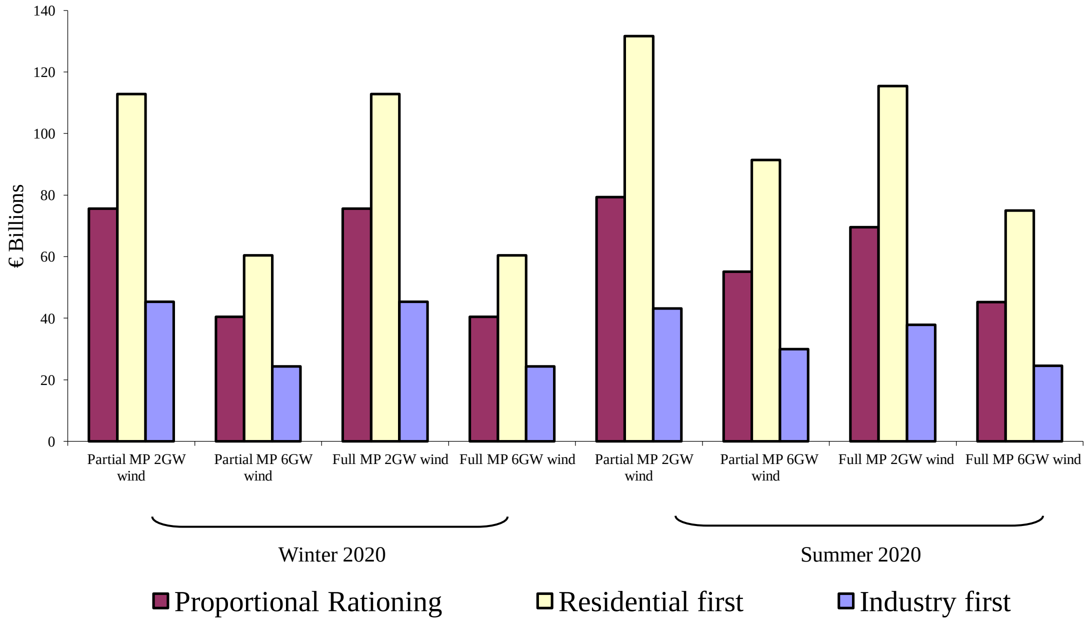
Figure 6 shows the cost of a 3 week shortage in 2020. As in 2008, 3 weeks in January and July are analysed. Again, it is the case that the cost of the shortage will be lower if 6000 MW of wind are installed. However, potential to produce electricity from wind in summer is reduced, and so, our results show that the cost of a shortage in summer can actually exceed that of winter.

Figure 6. Cost of 3 week electricity shortages in 2020



The costs of a 3 month gas shortage in 2020 are displayed in figure 7. The same months are chosen in both 2008 and 2020. If either proportional rationing or residential rationing is pursued, the cost of the outage is highest in summer when only 2000 MW of wind are installed. In winter, the cost is almost as high but more wind can be used to meet the shortfall in electricity. If industrial rationing is pursued, the cost is highest in the low wind, winter scenario.

Figure 7. Cost of 3 month electricity shortages in 2020



Whether the shortage lasts 1 day, 3 weeks or 3 months the best response is to ration electricity in the industrial sector first and then the commercial sector (as it has the next lowest VoLL). Because the VoLL is highest for households, this sector should be left unaffected for as long as possible. It would be cheaper to ration electricity in proportion to usage in all sectors than to cut off residential users first. Results also show that the cost of an electricity shortage is higher in 2020 than in 2008 if only 2000 MW of wind are installed by 2020. However, if 6000 MW of wind are installed, then, the costs in 2020 could be lower than the costs of similar shortages in 2008.

3.2 Consumer Surplus and Producer Surplus

We have examined the cost of losing electricity as a result of a disruption to the natural gas supply in the residential sector. However, households also use natural gas for heating and cooking. Table 1 displays the consumer surplus that is lost as a result of a natural gas disruption to the residential sector for various time periods. With regard to one day outages, the loss is greatest in winter on midweek days, however in summer, bigger losses can be observed at weekends. As expected, if outages are to last 3 weeks or 3 months, the loss in winter far outweighs that of summer. This is because more gas is demanded in winter for space heating and water heating. The cost of an outage in 2020 is expected to far exceed that of 2008. This is mainly driven by the expected increase in gas usage and natural gas connections in both ROI and NI.

Table 1. Loss of consumer surplus as a result of residential gas outages

Elasticity = -0.16	€s	€s	€s
2008	**ROI**	**NI**	**Total 2008***
1 day			
Midweek winter	8,237,231	1,656,415	9,893,645
Weekend winter	6,256,090	1,258,030	7,514,120
Midweek summer	1,489,279	299,477	1,788,756
Weekend summer	1,629,835	327,741	1,957,576
3 weeks			
Winter	160,511,007	32,276,961	192,787,969
Summer	34,196,207	6,876,473	41,072,680
3 months			
Winter	680,020,558	136,744,499	816,765,056
Summer	152,181,154	30,601,921	182,783,076
2020	**ROI**	**NI**	**Total 2020***
1 day			
Midweek winter	16,575,412	3,333,129	19,908,541
Weekend winter	12,588,852	2,531,477	15,120,329
Midweek summer	2,977,725	598,787	3,576,512
Weekend summer	3,258,758	655,300	3,914,058
3 weeks			
Winter	322,989,148	64,949,491	387,938,640
Summer	68,373,299	13,749,103	82,122,402
3 months			
Winter	1,368,375,068	275,164,862	1,643,539,930
Summer	304,277,247	61,186,738	365,463,985

*Constant prices, 2004=100

Table 1 assumes that the price elasticity of demand for natural gas is -0.16. Table 2 shows that consumer surplus increases significantly if the elasticity changes to -0.01. Although still inelastic, an elasticity closer to zero means that demand is more responsive to changes in price and so, at higher prices, consumers reduce their consumption of natural gas. Alternatively, an elasticity of -.50 results in a much lower consumer surplus because consumers react weakly to changes in price.

Table 2. Consumer surplus sensitivity analysis

Elasticity	-0.50		-0.01	
	2008	**2020**	**2008**	**2020**
	€s	€s	€s	€s
1 day				
Midweek winter	3,489,991	7,022,754	156,319,593	314,554,951
Weekend winter	2,650,612	5,333,708	118,723,094	238,901,193
Midweek summer	630,985	1,261,618	28,262,346	56,508,895
Weekend summer	690,537	1,380,687	30,929,701	61,842,114
3 weeks				
Winter	68,006,112	136,845,669	3,046,049,907	6,129,430,505
Summer	14,488,421	28,968,744	648,948,341	1,297,533,954
3 months				
Winter	288,114,534	579,760,040	12,904,887,892	25,967,930,896
Summer	64,476,878	128,917,716	2,887,972,594	5,774,330,966

Table 3 shows the losses that suppliers of gas to the residential sector face in the case of a natural gas disruption. The highest losses coincide with periods of highest demand.

Table 3. Loss of producer surplus for suppliers of residential gas

2008	**ROI**	**NI**	**Total 2008***
	€s	€s	€s
1 day			
Midweek winter	1,231,877	247,717	1,479,594
Weekend winter	935,598	188,138	1,123,736
Midweek summer	216,074	43,450	259,524
Weekend summer	236,466	47,551	284,017
3 weeks			
Winter	24,004,404	4,827,016	28,831,420
Summer	4,961,395	997,681	5,959,076
3 months			
Winter	101,697,000	20,450,125	122,147,125
Summer	22,079,375	4,439,914	26,519,290
2020	**ROI**	**NI**	**Total 2020***
1 day			
Midweek winter	2,247,029	451,852	2,698,881
Weekend winter	1,706,595	343,177	2,049,772
Midweek summer	403,672	81,174	484,846
Weekend summer	441,770	88,835	530,605
3 weeks			
Winter	43,785,701	8,804,813	52,590,514
Summer	9,268,958	1,863,883	11,132,841
3 months			
Winter	185,502,398	37,302,449	222,804,847
Summer	41,249,041	8,294,719	49,543,760

*Constant prices, 2004=100

3.3. Reduction in government revenue

Table 4 shows the effect of gas and electricity shortages on government revenue in the Republic of Ireland. As stated previously, only residential users of gas and electricity are required to pay VAT at 13.5%. Industrial and commercial enterprises in the Republic of Ireland do not pay any VAT on electricity or natural gas. The degree to which VAT falls depends on the duration of the outage, the time of year at which the outage occurs and the amount of wind on the system. Moneypoint availability is only important for outages that occur during the summer. As expected, losses are generally higher in winter than in summer. However, in 2020 we see that lost VAT on the sale of electricity can be greater in summer than in winter. This happens because in summer a lack of wind hinders the production of wind powered electricity. Thus, the gap between the supply and demand for electricity can be larger in winter than in summer, even if the total level of demand is higher in winter.

Table 4. Reduction in VAT revenue

2008	**Lost revenue: VAT on Gas**	**Lost revenue: VAT on Electricity**	
	€s	€s	
1 day		**Partial MP**	**Full MP**
Midweek winter	387,654	1,070,530	1,070,530
Weekend winter	294,419	785,343	785,343
Midweek summer	67,995	1,171,186	992,195
Weekend summer	74,413	711,063	542,043
3 weeks			
Winter	7,553,833	18,968,891	18,371,980
Summer	1,561,278	20,948,537	18,433,734
3 months			
Winter	6,948,055	81,028,124	76,117,683
Summer	32,002,553	84,657,690	73,749,401

2020	**Lost revenue: VAT on Gas**	**Lost revenue: VAT on Electricity**			
	€s	€s			
1 day		**Partial MP 2GW wind**	**Full MP 2 GW wind**	**Partial MP 6GW wind**	**Full MP 6 GW wind**
Midweek winter	707,107	1,920,768	1,920,768	1,495,860	1,495,860
Weekend winter	537,040	1,592,019	1,592,019	1,167,032	1,167,032
Midweek summer	127,030	1,708,420	1,520,480	850,529	703,838
Weekend summer	139,019	1,453,819	1,092,635	510,291	287,544
3 weeks					
Winter	13,778,717	32,484,655	32,484,655	15,677,551	15,677,551
Summer	2,916,805	38,926,837	32,901,679	27,113,990	21,472,053
3 months					
Winter	58,374,880	137,175,112	137,175,112	73,477,593	73,477,593
Summer	12,980,467	156,343,957	137,133,855	108,582,156	89,042,665

3.4 The total cost of a natural gas disruption

The total cost of a natural gas disruption includes the cost of both lost electricity and lost natural gas. For the residential sector, the cost of the natural gas outage and the subsequent electricity outage are estimated separately. As stated earlier however, we estimate the value of a unit of energy (gas and electricity) to the industrial and commercial sectors by dividing GVA by electricity and gas demand combined and we multiply this term by the kWhs of energy that are lost over a particular time period. We estimate the total cost of a natural gas disruption assuming that rationing is carried out in proportion to the amount of electricity and gas demanded in each sector in ROI and NI. On average, the cost of proportional rationing is about 60% of the cost that would result if rationing were carried out in the residential sector first. On the other hand, rationing the industrial sector first would cost about 50% of that of proportional rationing, on average.

The costs of natural gas disruptions over different time periods in 2008 and 2020 are displayed in appendix 5. The cost of the electricity outage is also shown for comparison purposes. As expected, the cost of an outage is greater in winter than summer due to higher demand. Also, the cost is greater on midweek days than it is on weekend days. This can be attributed to the fact that disruptions to the industrial and commercial sector are more costly on midweek than weekend days. The table shows that the cost of electricity outages, caused by disruptions to the supply of natural gas, are, on average, 86% of the total cost of the disruption.[16] In summer, the loss of natural gas in the industrial, commercial and residential sector add little to the overall cost of the disruption because the demand for heating by natural gas is very low at this time of year.

4. Discussion

4.1 Gas in Ireland

Natural gas accounted for 13% of all energy used in Ireland in 2008 (SEAI, 2009) and it represented over 60% of all fuel used in power generation (SEAI, 2009). These figures are set to increase (see appendix 6). The majority of gas demanded in ROI and NI is currently supplied with imports from Moffat in western Scotland while the remainder is supplied from the Kinsale gas field and satellite fields off the south coast of Ireland. The first Scotland-Ireland interconnector was built in 1993. The second, built in 2002, was intended to provide

[16] Please note that these costs are not directly comparable. The value of a unit of electricity is derived by dividing GVA by electricity use. However, the cost of a unit of energy (gas plus electricity) for non residential users is estimated by dividing GVA by electricity and gas usage. Thus, the value of a unit of energy is lower than the value of an electricity unit. Nevertheless, the total cost of the outage will be higher than the cost of an electricity outage alone because the value of a unit of energy is multiplied by the number of units of gas and electricity that are lost. The total cost also includes the loss in consumer surplus.

security of supply in the event of a supply disruption to the first interconnector – it is therefore seldom used.

The Corrib gas field off the west coast of Ireland is currently being developed. Corrib is expected to supply 62.8% of Irish demand (39% of peak day demand) when it goes live in 2012 or 2013. However, it is also forecast that Corrib gas will decline quickly and reduce to less than 50% of its peak production within 6 years. Unless new sources of supply are brought on stream, Irish dependence on imports from Great Britain will rise again. The production of shale gas in the USA has encouraged some European countries to think about exploring the opportunity for shale gas in Europe. However, building the required infrastructure takes time and is costly.

Shannon LNG proposes to begin construction on a liquefied natural gas (LNG) regasification terminal[17] on the Shannon Estuary in Co. Kerry. At its normal operating flowrate, it would supply 60% of Ireland's gas demand (Arup, 2007). A number of other potential gas prospects have also been identified in the Celtic Sea. The presence of gas in both the Old Head of Kinsale and Schull has been confirmed and technical and commercial viability is currently being assessed. Other potential prospects such as the West Dooish and Cashel prospects have been identified but the commercial viability of these has yet to be established.

There is currently only a small amount of storage in Ireland at Kinsale (200 million cubic metres (mcm)) which accounts for about 3% of annual demand but this is expected to decline in the coming years. At the end of 2005, the average number of days of gas storage in Ireland was 11 whereas for the EU-15 it was 52 (CER, 2008). Islandmagee Storage Limited proposes to develop a 500 mcm salt cavity storage facility under Larne Lough. The first gas operations are expected to begin there in 2014.

4.2 Implications of a natural gas shortage

In this study we consider the cost of a gas shortage in terms of lost production. However, there may be other costs. If the shortage is prolonged there may be damage to equipment and plants (especially if weather is below freezing) and there may be delays in restarting production after the shortage. Ilex Energy Consulting (2006a) studied the effects of shortages on the industrial sector and pointed out that there may even be a loss of market share as some companies would be forced to relocate and job losses may result. We have not been able to quantify such costs in this paper. However, they are probably small. A long disruption of gas supply is more likely to be Europe-wide than limited to Ireland. Relocation within Europe would be pointless.

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[17] A regasification plant is one in which LNG is taken off of a ship, moved into cold storage tanks and then regasified back into natural gas to send to market.

Ilex Energy Consulting (2006a) noted that some sectors are able to run on back-up fuel and those that can generally have enough fuel for one day. These companies tend to be in refining, paper, steel, glass, some heavy food and some chemical industries. The amount of gas that needs to be retained varies by activity. Generally 10-20% of normal demand would be enough to keep some production going in most energy intensive industries but the likes of ammonia and aluminium would require a much higher proportion (Ilex Energy Consulting, 2006a). However, there are low stocks of finished product in most sectors so even a 1 day stoppage would adversely affect downstream customers. It is likely that the same issues would arise in the commercial sector.

Another consequence of a natural gas shortage is that increased prices may result for consumers. Depending on the industry, an increase in the price of gas may represent a substantial increase in overall costs and reduced production may result. Weak consumer confidence could also deter potential gas customers in all sectors. We have already noted that gas demand in the residential sector is inelastic. If increased prices are prolonged the rate of fuel poverty may also increase.[18]

Disruptions to the natural gas supply will force those who rely on natural gas for space heating, water heating or cooking to further increase the demand for electricity, which would put further pressure on an already limited supply. Also, people may be forced to use old or inefficient heating or cooking systems which would increase the risk of fires or accidents. Fuel poverty and its associated health problems are substantial issues in Ireland but concentrated in poor households that use solid fuels as their primary source for heating (Scott et al., 2008). A gas shortage would disproportionally hit the better-off, who on the one hand are not used to coping with rationed energy but on the other hand would have the means to pay for alternative heating. It is likely, however, that a prolonged disruption of the gas supply in a cold winter[19] would cause health problems for at least some people. Thus, we may have underestimated the costs associated with electricity outages.

Gas supply disruptions in the past have encouraged countries to think about ways of ensuring long term gas security. One way of doing this would be to build a strategic storage facility. Ilex Energy Consulting (2006b) warns that a strategic storage facility should not be utilised in short periods of high demand. Instead the commercial market should be allowed to operate as normal and strategic storage should only be availed of in cases of persistent market tightness.

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18 Based on expenditure, 15.9% of households in Ireland were fuel poor in 2005. The fuel poverty rate had increased to over 19% by quarter 1 of 2008 (Scott et al., 2008).

19 Note that Ireland's climate is very temperate; while night time temperatures regularly fall below freezing point, day time temperatures rarely do so.

The costs associated with storage include the initial cost of building the plant and the associated transport costs. The costs depend on the amount of cushion gas[20] required as well as the capital expenditure. If one were to include transit costs from Europe to UK, for example, up to 1 billion pounds could be added to the overall cost (Ilex Energy Consulting, 2006b). Ilex Energy Consulting (2006b) estimates the benefit of developing strategic storage. For a 3.3 billion cubic meter (bcm) plant with a 30 year life span which would be built over 3 years, the net present value is £8.6 billion. This assumes a real interest rate of 3.5% but results show that a substantial benefit can be gained even if the interest rate increases. There are different types of storage options, all of which have advantages and disadvantages. The report published by Ilex Energy Consulting (2006b) shows that building a storage facility in a depleted field is cheaper than using salt cavern or LNG storage.[21] It is thought that the storage facility at Larne in NI will take 7 years to develop at a cost of £250 million. The plant (500 mcm) should be able to supply over 60 days of peak demand in NI in the case of a shortage. This same shortage would have cost over £6 billion in 2008[22] if rationing was carried out in proportion to usage across sectors. 60% of this cost would be endured by the residential sector. Based on these figures, a storage facility in ROI which could supply 90 days peak demand would probably cost about €1.35 billion.[23] In comparison, a gas disruption resulting in electricity shortages for 90 winter days would have cost €51 billion in 2008 if each sector were rationed proportionally. The cost would have been over €14 billion were the industrial sector preferentially rationed or, in the worst case scenario, the cost could have reached over €73 billion were the residential sector preferentially rationed.

Due to Ireland's location, ensuring new suppliers through the building of interconnectors between Ireland and countries other than the UK is difficult. The opening of the Corrib gas pipeline will increase Ireland's security of supply but only in the short to medium term. If the Shannon LNG plant were to become operational it would serve average all Ireland demand for 25 days or all Ireland demand in retail and commercial sector for 116 days. According to Shannon LNG (2006), LNG in Ireland will enable the sourcing of gas from multiple sources which will lead to greater gas price competition. The project sponsors estimate that the Shannon project will have a lifespan of about 50 years and it is estimated that it would contribute €1.35 billion (in 2007 prices) to Irish GNP over a 30 year period (DKM, 2008). However, Moselle and Harris (2007) argue that benefits from LNG are not guaranteed. First, many commentators are of the opinion that LNG re-gasification capacity exceeds LNG production capacity and this trend is set to continue to the near future. LNG cargoes will be

[20] This is the volume of gas needed as a permanent inventory to maintain adequate reservoir pressures and deliverability rates throughout the withdrawal season.

[21] To provide 3.3 bcm of storage a depleted field costs £1,843, salt cavern storage costs £2,485 and LNG storage costs £2,478.

[22] Total GVA in NI in 2008 was £28.7 billion (ONS, 2009).

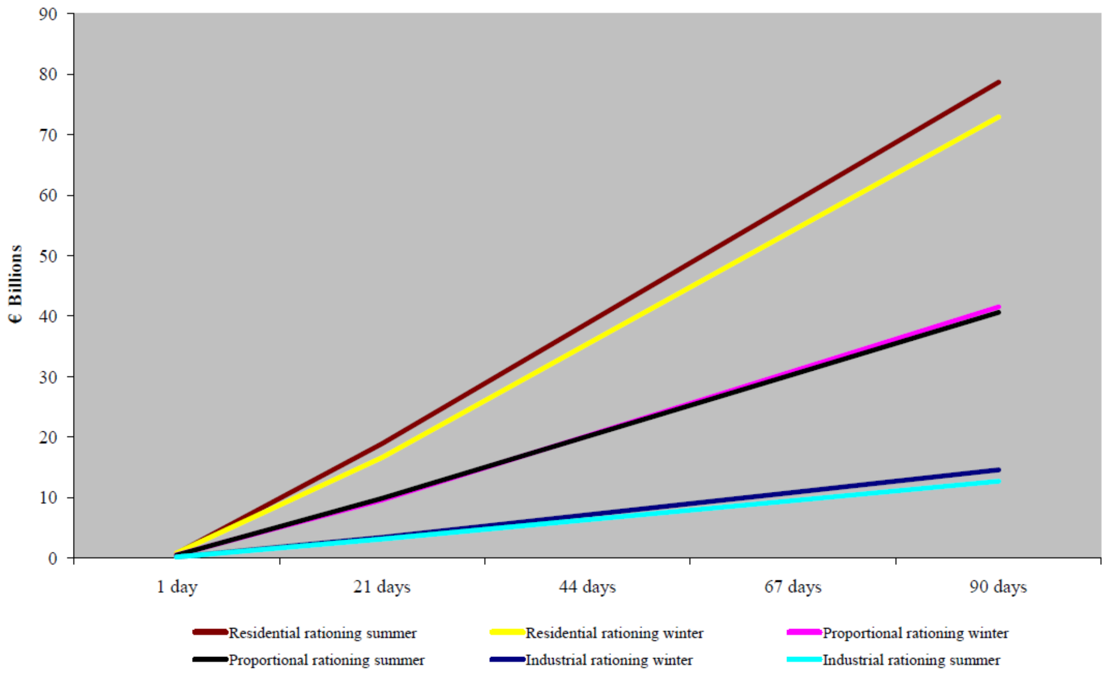
[23] This is a crude estimate based on the NI figure. We impute the ROI cost based on storage cost per day of the NI project and we weight by the population. We then convert to euro assuming £1=€1.2

diverted towards markets with the highest prices and so, LNG terminal utilisation could be extremely variable. Second, the CER (2009c) estimates that the cost of Shannon LNG will be €10 per connected customer. Mosselle and Harris (2007), on the other hand, calculate that the cost will be €390 per customer, assuming that the cost of the project will be €400 million. Even if costs are allocated in relation to the capacity of each customer's connection, residential customers will still pay over €100 each (Mosselle and Harris, 2007). Also, if both Corrib and the Shannon LNG facility were in operation, the second gas interconnector and, perhaps even the first, would be redundant but Irish consumers would still be paying for them. This is another consideration that should be taken into account if investment in Shale gas infrastructure comes onto the agenda.

We have not assessed the probability of a shortage in this paper. Recent commentary suggests that the main threat to the European gas supply is disruptions in the transport of Russian gas. However, since most of Ireland's imports come from the UK and the UK in turn only sources 2% of its imported gas from Russia (Watson, 2010), one might conclude that Ireland's gas supply is not inherently insecure. While indigenous production in the UK is expected to fall, the increased imports are not expected to be sourced from Russia (Watson, 2010). In general, however, European gas demand is increasing and with that is Europe's dependence on Russia. The Russia-Ukraine gas price disputes have already led to gas supply disruptions in several EU countries in recent years, the worst of which occurred in 2006 and 2009.

The implications of gas outages will vary by time of year and by the rationing policies pursued. Figure 8 shows the costs of a hypothetical electricity outage that arises as a result of a shortage of natural gas. Figure 8 shows how the costs would have been distributed in the winter and summer of 2008. If a gas disruption cannot be avoided, and if supplies of stored gas cannot be drawn upon, the best response is always to ration gas in the industrial sector first. The graph also shows that the most expensive outages do not coincide with periods of highest demand. This is because in summer, electricity production from gas cannot be substituted with wind to the degree that it can in winter.

Figure 8. The cost of electricity outages in 2008



5. Conclusion

In this paper we estimate the cost of disruptions in the supply of natural gas. The cost of losing one day of gas-fired electricity amounts to 0.1-1.0 billion euro, depending on the time of week, the time of year, and the rationing scheme used. It would be cheaper to cut power to industry first, but current black-out protocols do the opposite. The cost of losing three months of gas-fired power could be as high as 80 billion euro or 50% of GDP. Losing gas for heating for three months would add another 8 billion euro on average.

There are some limitations associated with the approach that we have used. We have not been able to take into account the costs associated with the extra time that may be needed to restart business/production processes after the disruption of supply. There may be costs of having to replace damaged stock or equipment which we have not quantified. We assume that the demand for gas and electricity do not change it the supply of electricity and gas is disrupted. We do not have a detailed characterisation of the use of electricity and therefore do not know the exact implications of a prolonged black-out; this particularly affects our estimates of the residential value of a lost load of electricity. The loss of electricity in one industry may adversely affect upstream and downstream customers but this is omitted from the analysis. In the case of a prolonged shortage limited to Ireland, a loss of market share may occur and investment into Ireland may be diverted elsewhere. However, a gas shortage is more likely to affect a wider area, in which case we ignore the impact of economic mayhem in Ireland's international trading partners. We omit the implications of switching to alternative fuels, particularly for home heating, such as coal, peat and firewood. We also ignore the implications for health.

At present it is policy to turn off electricity in the residential sector first. Given that the cost of disruptions in this sector far outweighs those in the industrial and commercial sectors, this policy should be reversed. We have also shown that the demand for natural gas in the residential sector is inelastic and changes only in response to changes in the weather. This further strengthens our argument that the supply of gas to households should not be disproportionately rationed. In the case of a 3 month gas supply outage in the winter of 2020, over €6 billion could be saved if electricity were rationed in the industrial rather than the residential sector.

The demand for natural gas in Ireland is increasing. New sources of supply are coming on stream that will increase Ireland's security of supply and will reduce Ireland's dependence on imported gas. There are costs and risks associated with investing in new infrastructure and even then Ireland will not be totally self-sufficient in the supply of gas. Yet, by having a more diverse supply Ireland will be less vulnerable if disruptions to the international gas supply occur. The current level of gas storage in Ireland is inadequate, thus prohibiting any mitigation of the high costs of gas disruptions. We have shown that the costs associated with gas disruptions in Ireland would far outweigh the cost of investing in a 90 day storage facility.

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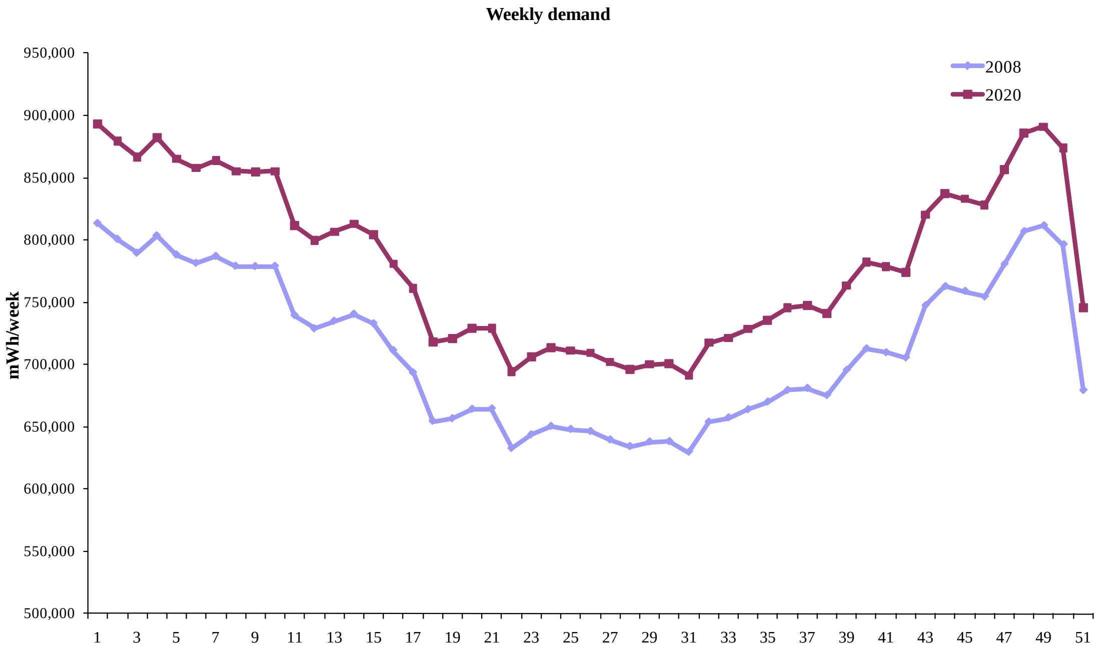
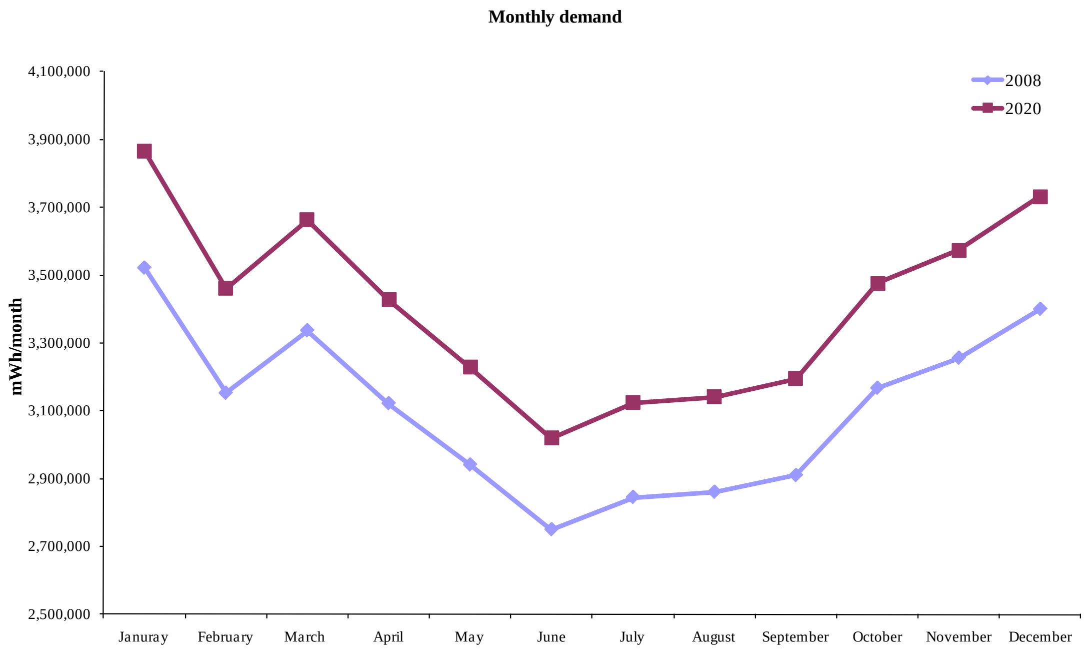
Appendix 1a. Weekly electricity demand profiles 2008 and 2020



Appendix 1b. Monthly electricity demand profiles 2008 and 2020



Appendix 2. Characteristics of natural gas customers in the residential sector

	All households		Households with gas		Gas users as % of total
	Freq.	%	Freq.	%	
Number of households	6884	100	2046	100	29.72%
Region					
Border, Midland And West	2,014	29.3	107	5.23	5.31%
South West, South East, Mid West, Mid East	2,893	42.09	604	29.52	20.88%
Dublin	1,967	28.62	1,335	65.25	67.87%
Urban /Rural					
Urban Households	4,523	65.8	1,954	95.5	43.20%
Rural Non-Farm Households	1,731	25.18	52	2.54	3.00%
Rural Farm Households	620	9.02	40	1.96	6.45%
Tenure					
Owned Outright	3,223	46.89	717	35.04	22.25%
Owned Mortgage	2,441	35.51	866	42.33	35.48%
Owned Tenant Purchase Scheme	35	0.51	16	0.78	45.71%
Rent Local Authority	475	6.91	171	8.36	36.00%
Rent Private Owner - Furnished	515	7.49	216	10.56	41.94%
Rent Private Owner - Unfurnished	113	1.64	36	1.76	31.86%
Rent Free	72	1.05	24	1.17	33.33%
Type Of Accommodation					
Bedsitter	10	0.15	3	0.15	30.00%
Converted Apartment/Flat	61	0.89	27	1.32	44.26%
Large Block Custom Built Apartment/Flat	48	0.7	27	1.32	56.25%
Small Block Custom Built Apartment/Flat	51	0.74	19	0.93	37.25%
Detached House	3,577	52.04	356	17.4	9.95%
Semi-Detached/Terraced House	3,098	45.07	1,602	78.3	51.71%
Other	29	0.42	12	0.59	41.38%
No Bedrooms					
0	9	0.13	3	0.15	33.33%
1	186	2.71	74	3.62	39.78%
2	739	10.75	303	14.81	41.00%
3	3,008	43.76	1,001	48.92	33.28%
4	2,213	32.19	523	25.56	23.63%
5	532	7.74	109	5.33	20.49%
6	133	1.93	22	1.08	16.54%
7	42	0.61	9	0.44	21.43%
8	12	0.017	2	0.1	16.67%
No Children Under 17					
0	4,067	59.16	1,224	59.82	30.10%
1	987	14.36	305	14.91	30.90%
2	1,008	14.66	307	15	30.46%
3	577	8.39	158	7.72	27.38%
4	181	2.63	37	1.81	20.44%
5	41	0.6	9	0.44	21.95%
6	6	0.09	4	0.2	66.67%
7 or more	7	0.1	2	0.1	28.57%
No Persons					
1	1,361	19.8	428	20.92	31.45%
2	1,895	27.57	574	28.05	30.29%
3	1,185	17.24	378	18.48	31.90%

	All households		Households with gas		Gas users as % of total
	Freq.	%	Freq.	%	
4	1,214	17.66	356	17.4	29.32%
5	770	11.2	213	10.41	27.66%
6	324	4.71	74	3.62	22.84%
7	84	1.22	14	0.68	16.67%
8 or more	41	0.6	9	0.44	21.95%
Single parent	254	3.7	100	4.89	39.37%
Age Chief Economic Supporter (CES)					
15-24 Years	305	4.44	96	4.69	31.48%
25-34 Years	1,115	16.22	412	20.14	36.95%
35-44 Years	1,706	24.82	543	26.54	31.83%
45-54 Years	1,421	20.67	398	19.45	28.01%
55-654 Years	964	14.02	236	11.53	24.48%
65-74 Years	805	11.71	220	10.75	27.33%
75+ Years	556	8.09	141	6.89	25.36%
Sex CES					
Male	4,440	64.59	1,270	62.07	28.60%
Female	2,434	35.41	776	37.93	31.88%
Social Class CES					
Professionals or Farmers >200 acres	528	7.68	189	9.24	35.80%
Managerial And Technical or Farmers 100-199 acres	1,921	27.95	676	33.04	35.19%
Non-Manual or Famers 50-99 acres	1,101	16.02	363	17.74	32.97%
Skilled Manual or Farmers 30-49 acres	1,317	19.16	305	14.91	23.16%
Semi-Skilled Manual or Farmers <30 acres	678	9.86	181	8.85	26.70%
Unskilled Manual	422	6.14	98	4.79	23.22%
Other	907	13.19	234	11.44	25.80%
Education level CES					
No Formal Education	21	0.31	8	0.39	38.10%
Primary Education	1,333	19.39	283	13.83	21.23%
Junior Cert/O Level	1,474	21.44	379	18.52	25.71%
Leaving Cert/ A Level	1,825	26.55	541	26.44	29.64%
Sub Degree	851	12.38	267	13.05	31.37%
Primary Degree	776	11.29	315	15.4	40.59%
Higher Degree	512	7.45	221	10.8	43.16%
Missing education observations	82	1.19	32	1.56	39.02%
		Mean	**Std. Err.**	**Mean**	**Std. Err.**
Weekly expenditure on electricity		12.83	0.12	12.59	0.22
Weekly expenditure on gas		3.98	0.10	12.69	0.24
Weekly energy use in kWh		506.27	4.85	579.76	9.24
Weekly gross household income		987.96	10.18	1174.23	22.12
Weekly disposable household income		843.28	7.95	972.81	16.53

Source: CSO, 2008

Appendix 3. Cost per person of 1 day electricity shortage in 2008 and 2020*

	Proportional Rationing €M	Preferentially Rationing Residential €M	Preferentially Rationing Industry €M	Shortfall (% of demand)
1 day outage 2008				
Midweek Jan Partial MP	85	135	31	40.28%
% GVA	0.05%	0.07%	0.02%	
Midweek Jan Full MP	85	135	31	40.28%
% GVA	0.05%	0.07%	0.02%	
Weekend Jan Partial MP	73	138	23	33.10%
% GVA	0.04%	0.07%	0.01%	
Weekend Jan Full MP	73	138	23	33.10%
% GVA	0.04%	0.07%	0.01%	
Midweek July Partial MP	79	124	32	46.65%
% GVA	0.04%	0.07%	0.02%	
Midweek July Full MP	67	108	24	39.52%
% GVA	0.04%	0.06%	0.01%	
Weekend July Partial MP	58	116	17	32.70%
% GVA	0.03%	0.06%	0.01%	
Weekend July Full MP	44	90	13	24.93%
% GVA	0.02%	0.05%	0.01%	
1 day outage 2020				
Midweek Jan Partial MP 2GW wind	149	211	94	62.70%
% GVA	0.06%	0.08%	0.04%	
Midweek Jan Partial MP 6GW wind	116	164	73	48.83%
% GVA	0.04%	0.06%	0.03%	
Midweek Jan Full MP 2GW wind	149	211	94	62.70%
% GVA	0.06%	0.08%	0.04%	
Midweek Jan Full MP 6GW wind	116	164	73	48.83%
% GVA	0.04%	0.06%	0.03%	
Weekend Jan Partial MP 2GW wind	143	237	78	58.21%
% GVA	0.05%	0.09%	0.03%	
Weekend Jan Partial MP 6GW wind	105	174	57	42.67%
% GVA	0.04%	0.07%	0.02%	
Weekend Jan Full MP 2GW wind	143	237	78	58.21%
% GVA	0.05%	0.09%	0.03%	
Weekend Jan Full MP 6GW wind	105	174	57	42.67%
% GVA	0.04%	0.07%	0.02%	
Midweek July Partial MP 2GW wind	113	163	69	59.04%
% GVA	0.04%	0.06%	0.03%	
Midweek July Partial MP 6GW wind	56	81	35	29.39%
% GVA	0.02%	0.03%	0.01%	
Midweek July Full MP 2GW wind	100	145	62	52.54%

	Proportional Rationing	Preferentially Rationing Residential	Preferentially Rationing Industry	Shortfall (% of demand)
% GVA	0.04%	0.06%	0.02%	
Midweek July Full MP 6GW wind	46	67	29	24.32%
% GVA	0.02%	0.03%	0.01%	
Weekend July Partial MP 2GW wind	125	232	59	58.00%
% GVA	0.05%	0.09%	0.02%	
Weekend July Partial MP 6GW wind	44	81	21	20.36%
% GVA	0.02%	0.03%	0.01%	
Weekend July Full MP 2GW wind	94	174	44	43.59%
% GVA	0.04%	0.07%	0.02%	
Weekend July Full MP 6GW wind	25	46	12	11.47%
% GVA	0.01%	0.02%	0.00%	

∗ Constant prices 2004=100

Appendix 4. Cost per person of 3 week and 3 month electricity shortages in 2008 and 2020*

	Proportional Rationing €B	Preferentially Rationing Residential €B	Preferentially Rationing Industry €B	Shortfall (% of demand)
3 week outage 2008				
Winter Partial MP	1,549	2,685	551	35.56%
% GVA	5.19%	9.00%	1.85%	
Winter Full MP	1,500	2,601	533	34.45%
% GVA	5.03%	8.72%	1.79%	
Summer Partial MP	1,597	3,054	507	41.15%
% GVA	5.35%	10.24%	1.70%	
Summer Full MP	1,405	2,688	446	36.21%
% GVA	4.71%	9.01%	1.50%	
3 week outage 2020				
Winter Partial MP 2GW wind	2,592	3,790	1,583	52.79%
% GVA	6.73%	9.85%	4.11%	
Winter Partial MP 6K wind	1,251	1,829	764	25.48%
% GVA	3.25%	4.75%	1.99%	
Winter Full MP 2GW wind	2,592	3,790	1,583	52.79%
% GVA	6.73%	9.85%	4.11%	
Winter Full MP 6K wind	1,251	1,829	764	25.48%
% GVA	3.25%	4.75%	1.99%	
Summer Partial MP 2GW wind	2,880	4,727	1,582	66.34%
% GVA	7.48%	12.28%	4.11%	
Summer Partial MP 6K wind	2,006	3,292	1,102	46.21%
% GVA	5.21%	8.55%	2.86%	
Summer Full MP 2GW wind	2,434	3,995	1,337	56.07%
% GVA	6.32%	10.38%	3.47%	
Summer Full MP 6K wind	1,589	2,607	873	36.59%
% GVA	4.13%	6.77%	2.27%	
3 month outage 2008				
Winter Partial MP	6,706	11,777	2,353	36.23%
% GVA	22.47%	39.47%	7.89%	
Winter Full MP	6,300	11,063	2,210	34.03%
% GVA	21.11%	37.08%	7.41%	
Summer Partial MP	6,557	12,702	2,050	37.59%
% GVA	21.97%	42.57%	6.87%	
Summer Full MP	5,712	11,065	1,786	32.75%
% GVA	19.14%	37.08%	5.98%	
3 month outage 2020				
Winter Partial MP 2GW wind	11,141	16,637	6,686	53.21%
% GVA	28.94%	43.22%	17.37%	
Winter Partial MP 6K wind	5,968	8,911	3,581	28.50%
% GVA	15.50%	23.15%	9.30%	
Winter Full MP 2GW wind	11,141	16,637	6,686	53.21%
% GVA	28.94%	43.22%	17.37%	
Winter Full MP 6K wind	5,968	8,911	3,581	28.50%

	Proportional Rationing	Preferentially Rationing Residential	Preferentially Rationing Industry	Shortfall (% of demand)
% GVA	15.50%	23.15%	9.30%	
Summer Partial MP 2GW wind	11,697	19,401	6,354	60.22%
% GVA	30.39%	50.40%	16.51%	
Summer Partial MP 6K wind	8,123	13,474	4,413	41.83%
% GVA	21.10%	35.00%	11.46%	
Summer Full MP 2GW wind	10,260	17,017	5,573	52.82%
% GVA	26.65%	44.21%	14.48%	
Summer Full MP 6K wind	6,662	11,049	3,619	34.30%
% GVA	17.31%	28.70%	9.40%	

∗ Constant prices 2004=100

Appendix 5. Total cost of gas disruptions 2008 and 2020*: Proportional Rationing

	Total cost of disruption	cost per person	Cost of electricity outage only	cost per person	Cost of electricity outage as proportion of total cost
1 day outage 2008	**€M**	**€M**	**€M**	**€M**	
Midweek Jan Partial MP	639	103	525	85	82%
Midweek Jan Full MP	639	103	525	85	82%
Weekend Jan Partial MP	537	87	452	73	84%
Weekend Jan Full MP	537	87	452	73	84%
Midweek July Partial MP	537	87	489	79	91%
Midweek July Full MP	473	76	414	67	88%
Weekend July Partial MP	429	69	361	58	84%
Weekend July Full MP	353	57	276	44	78%
1 day outage 2020					
Midweek Jan Partial MP 2GW wind	1,086	160	1,012	149	93%
Midweek Jan Partial MP 6GW wind	910	134	788	116	87%
Midweek Jan Full MP 2GW wind	1,086	160	1,012	149	93%
Midweek Jan Full MP 6GW wind	910	134	788	116	87%
Weekend Jan Partial MP 2GW wind	1,007	148	970	143	96%
Weekend Jan Partial MP 6GW wind	796	117	711	105	89%
Weekend Jan Full MP 2GW wind	1,007	148	970	143	96%
Weekend Jan Full MP 6GW wind	796	117	711	105	89%
Midweek July Partial MP 2GW wind	780	115	764	113	98%
Midweek July Partial MP 6GW wind	478	70	380	56	80%
Midweek July Full MP 2GW wind	714	105	680	100	95%
Midweek July Full MP 6GW wind	426	63	315	46	74%
Weekend July Partial MP 2GW wind	874	129	846	125	97%
Weekend July Partial MP 6GW wind	414	61	297	44	72%
Weekend July Full MP 2GW wind	698	103	636	94	91%
Weekend July Full MP 6GW wind	306	45	167	25	55%
3 week outage 2008	**€B**	**€M**	**€B**	**€M**	
Winter Partial MP	12	1,930	10	1,549	80%
Winter Full MP	12	1,888	9	1,500	79%
Summer Partial MP	11	1,791	10	1,597	89%
Summer Full MP	10	1,623	9	1,405	87%
3 week 2020					

	Total cost of disruption	cost per person	Cost of electricity outage only	cost per person	Cost of electricity outage as proportion of total cost
Winter Partial MP 2GW wind	20	2,881	18	2,592	90%
Winter Partial MP 6GW wind	12	1,821	8	1,251	69%
Winter Full MP 2GW wind	20	2,881	18	2,592	90%
Winter Full MP 6GW wind	12	1,821	8	1,251	69%
Summer Partial MP 2GW wind	20	2,975	20	2,880	97%
Summer Partial MP 6GW wind	15	2,173	14	2,006	92%
Summer Full MP 2GW wind	17	2,520	17	2,434	97%
Summer Full MP 6GW wind	12	1,834	11	1,589	87%
3 month outage 2008					
Winter Partial MP	52	7,601	42	6,706	81%
Winter Full MP	49	7,281	39	6,300	79%
Summer Partial MP	46	6,826	41	6,557	88%
Summer Full MP	42	6,148	35	5,712	85%
3 month 2020					
Winter Partial MP 2GW wind	84	12,395	76	11,141	90%
Winter Partial MP 6GW wind	56	8,289	40	5,968	72%
Winter Full MP 2GW wind	84	12,395	76	11,141	90%
Winter Full MP 6GW wind	56	8,289	40	5,968	72%
Summer Partial MP 2GW wind	80	11,795	79	11,697	99%
Summer Partial MP 6GW wind	59	8,738	55	8,123	93%
Summer Full MP 2GW wind	71	10,476	70	10,260	98%
Summer Full MP 6GW wind	51	7,548	45	6,662	88%

∗ Constant prices 2004=100

Appendix 6. Energy Demand by Fuel (2008-2020)

Fuel	Total Final Demand excl power generation (ktoe)			Growth	Fuel Shares %		
	2008	2012	2020	08–20	2008	2012	2020
Coal	380	271	238	-37.3	3	2	2
Oil	8,534	7,835	9,607	12.6	64	62	64
Gas	1,659	1,778	2,056	24	12	14	14
Peat	280	214	147	-47.4	2	2	1
Renewables	254	348	381	50.4	2	3	3
Electricity	2,294	2,249	2,569	12	17	18	17
Total	13,401	12,695	15,000	11.9			
	Gross Electricity Consumption (gWh)			Growth	Fuel Shares %		
	2008	2012	2020	08–20	2008	2012	2020
Coal	4,259	6,060	1,966	-53.8	15	19	6
Oil	1,367	1,367	1,367	0	5	4	4
Gas	17,363	15,275	19,448	12	60	48	62
Peat	2,338	2,661	61	-97.4	8	8	0
Renewables	3,539	6,631	8,738	146.9	12	21	28
Electricity Imports	450	-2,822	1,230				
Total Generation	28,865	31,994	31,581	9.4			

Source: Walker et al. (2009).

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