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An Economic Evaluation of Future Electricity Use in Irish Data Centres

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Abstract: Data centres are a critical component of the modern, connected economy. They facilitate activities such as cloud computing, communication and data storage. In Ireland, the increasing presence and significant electricity demand of data centres is a growing concern for electricity generation and grid infrastructure. It is anticipated that future technological advances will drive efficiencies to help reduce energy demand. However, the specific technology and pattern of market adoption are currently unknown. This paper details recent developments in data centre cooling technology and applies an economic model of diffusion for the Irish data centre sector to model the adoption of a liquid cooling technology over the next decade. Results note that the pattern of market adoption for new technologies is key to modelling market changes, with consequences for national electricity consumption and the emissions associated with electricity generation. Estimates of the twelve-year reduction in national electricity demand from 2015-2026 range from 2.40% and 2.43% for New facilities only adopt (ND) and All facilities adopt (AD) scenarios, respectively.

Keywords: Data centres, energy, electricity consumption technology adoption, diffusion, ebergy forecasting.
JEL Keywords: Q40, Q47, O330

Primary discipline: Energy economics

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Disclaimer

This Working Paper contains research which is currently ongoing. The content, results and conclusions are subject to change. If you wish to provide feedback or are interested in potential collaboration, you can contact the main author via email: brcoyne@tcd.ie

1 Introduction

Society relies on the internet more in the 21st century than ever before. Although this is heterogeneous across countries, internet connectivity has been cited as a driver of economic activity (Koutroumpis, 2009; Pradhan et al., 2013; Whitacre et al., 2014). Universal internet access is a United Nations Sustainable Development Goal (UN, 2015) and the European Commission views internet infrastructure as “a key new type of economic asset” (European Commission, 2017a, 2017b). Innovations such as real-time computer processing, online transactions, social media (McKinsey, 2010), driverless cars (Macauley, 2016) and cloud-based computing (McKendrick, 2016) all require data which is typically stored on computer servers in a data centre, a facility dedicated to storing and transmitting electronic data. The increasing presence of data centres globally has gained the attention of industry and government stakeholders due to the potentially adverse impact on energy prices, energy network infrastructure investment and the security of energy supply.

This paper features two distinct components. The first provides a non-technical guide to the economic purpose of data centres and the key challenges and opportunities they present. This section touches economic activity, energy markets and climate change. The second component evaluates how a hypothetical energy efficiency for data centres could be adopted in the Irish context. The innovation is assumed to be direct liquid server cooling that would reduce data centre electricity consumption. To the author’s knowledge, this is the first paper to use an economic model of technology diffusion in the context of the data centre sector. This paper also considers the additional benefit of reduced carbon dioxide emissions associated with electricity generation. This work is the first in a series that will investigate wider energy system and macroeconomic consequences for the Irish economy.

The rest of the paper is laid out as follows: Sections 2 and 3 comprise the first component of this paper. Section 2 details recent trends in the data centre sector. Section 3 discusses relevant technical and economic literature, including the model of technology diffusion used later. The remainder or the paper considers the case study for the Republic of Ireland. Section 4 presents context for Ireland. Section 5 details the methodology and data used. Section 6 features the projections for electricity demand and emissions while Section 7 concludes.

2 Background

2.1 The importance of the internet

The demand for data centres is derived, in large part, from the demand for internet services. Previous research has shown that increasing internet penetration helps drive efficiency and economic growth. From 1990 to 2010, Pradhan et al. (2013) found evidence of a long run relationship between the proportion of a country with internet connectivity and economic growth, inflation and government expenditure. They present evidence of bi-directional causality for internet penetration and economic growth and for inflation and internet penetration from 1990-2010. Koutroumpis (2009) found a significant causal impact of increased broadband penetration on economic growth for OECD countries. Research has found the level of regional internet connectivity differ across low and high income countries, with network effects and firm competition being key determinants (Andrés et al., 2010). Lechman and Kaur (2016) suggest a link between increasing internet connectivity, internet connected technology (ICT) use and improved social progress in developing countries from 2000 to 2014. In the United States the adoption of an internet connection is associated with increased economic activity, higher income growth and lower unemployment growth in rural areas (Whitacre et al., 2014).

The United Nations cite affordable internet access as a Sustainable Development Goal (UN, 2015) and it is estimated that four billion people are currently without internet access (World Economic Forum, 2016). The volume of data in the economy will continue to grow rapidly in the coming years, with video content a key driver. CISCO estimate that by 2021 global annual internet traffic will be 3.3ZB (zettabyte, or one trillion gigabytes), almost triple the 2016 level of 1.2ZB (CISCO, 2017)[2]. In 1992, global internet traffic is estimated at 100 GB per day. In 2016, this has grown to over 26,000 GB per second. International Data Corporation estimates that the 'digital universe' will grow from 4.4ZB trillion gigabytes to

[2] See https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1426270

44ZB from 2013 to 2020 – more than doubling every two years[3]. The economic importance of internet connectivity means data centres will continue to be a critical infrastructure. The next section will discuss trends in the data centre sector.

2.2 The data centre sector

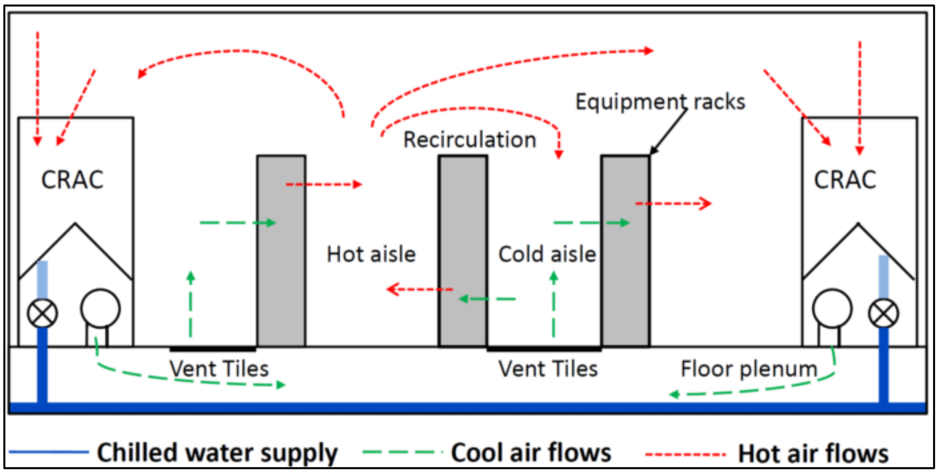
McKinsey (2010) notes that innovations such as real-time processing and online transactions have made economies reliant on data centres. To accommodate the rise in data demand, Gartner estimates global data centre systems expenditure in 2016 at $173bn, with a 2% rise expected in 2017 (Gartner, 2016). However, this conservative estimate excludes companies who build their own hardware for their data centre. Using commercial server shipment data, Koomey (2011) estimates that global data centre electricity consumption doubled from 2000 to 2005 and increased by 56% from 2005 to 2010[4]. However, this lower-than-expected rise in energy consumption is attributed to macroeconomic factors rather than efficiencies. Ebrahimi et al. (2014) estimate that US data centres consume between 1.3% to 2% of the US national electricity consumption. Globally, it is estimated that data centres consumed approximately 3% of energy and accounted for 2% of global emissions in 2015. This is expected to almost triple in the next decade (Bawden, 2016). Despite efficiencies, estimates note that data centre sectoral energy consumption in the US will rise by four per cent from 2014-2020, consuming 73 billion kWh in 2020 (Shehabi et al., 2016).

Figure 1 shows a conventional data centre, with servers arranged in 'hot' and 'cold' aisles to disperse heat. Mechanically chilled air is channelled through the floor into the servers. In contrast, a liquid-cooled facility would replace the mechanical air conditioner unit (CRAC) with a closed loop of fluid channelled through the server to remove heat effectively.

Figure 1: Traditional data centre layout

[3] See https://www.emc.com/leadership/digital-universe/2014iview/executive-summary.htm

[4] Analysis based on commercial sales of server components, omits 'hyper scale' facilities.



Source: Zhou et al. (2011)

Although there is some debate as to how much longer or in which form Moore's Law[5] will hold (Waldrop, 2016), there is general agreement on a continued increase in effective power density (Garimella et al., 2016). To mitigate this trend, advances in cooling technologies could offset rising energy demand. In the past, data centres were typically smaller, with companies leasing computer space. Today, colocation facilities are larger and 'hyper scale' data centres (typically built by one firm) operate over a large physical space. The next section will discuss how industry has worked to develop standards and efficiencies.

2.3 The role of industry

McKinsey notes that the data centre represents half of the company's corporate carbon footprint for some information-intensive firms (McKinsey, 2010). In theory, gains in energy efficiency should provide lower energy bills for data centre operators. Section 3.2 discusses economic reasons why there may be under-adoption of energy efficient technologies. There are several non-profit industry groups that promote energy efficiency. The Uptime Institute conservatively estimate that 20% of the servers in a data centre are underutilised, with 'comatose servers' that idle on standby[6]. An example is Visa, who identified and removed over 9,000 'comatose' servers. This reduced power consumption by 557 kW, reclaimed 3,000 square foot of floor space and saved $3.2 million annually[7].

Koomey and Taylor (2015) found that 30% of servers (from a sample of 4,000) across North America delivered no computing or information services in the six months prior to monitoring. Extended to the population, there are possibly 3.6 million comatose servers in the US and 10 million worldwide[8]. A follow up study on a larger sample found that a quarter of comatose servers were located in firms that took no action to remove them (Koomey and Taylor, 2017). This could reflect how companies prioritise zero downtime in their data centre more than any desire to improve energy efficiency. It also confirms that firms struggle to monitor their energy usage, which hinders their ability to evaluate potential

[5] Moore's Law, suggested by Gordon Moore around 1965, states that the number of transistors per square inch on a circuit effectively doubles approximately every two years.

[6] See https://journal.uptimeinstitute.com/2014-data-center-industry-survey/

[7] See https://uptimeinstitute.com/component/content/article/9-training-events/348-server-roundup-winners?Itemid=435

[8] Based on an IDC 2012 world server count of 35 million server units (Koomey and Taylor, 2015).

energy efficiencies. The Green Grid found that 97% of firms see areas where data centre monitoring could be improved. They report that only 29% of organisations can entirely quantify the environmental impact of their data centres[9].

There is also debate about the quality of the metric most commonly reported by firms- Power Usage Effectiveness (PUE), which is the ratio of the energy used by a data centre facility to the energy delivered just to the computing equipment within the facility. In a 2014 Uptime Institute survey of 1000 data centre managers, the average PUE is 1.7[10]. PUE is unreliable as it can vary depending on factors such as weather and computing loads. Brady et al. (2013) find that firms manipulate PUE values by including energy consumption that is not strictly for IT purposes. They also highlight that a low PUE does not mean a data centre is energy efficient, citing an example of data centre waste heat being reused outside of the facility not being factored into PUE. The failings of PUE to account for hardware efficiency, energy productivity and environmental performance are also cited by Horner and Azevedo (2016). Ebrahimi et al. (2014) note that rising energy costs are likely to spur adoption of more energy efficient technologies. However, imperfect information regarding data centre energy consumption may hinder any upgrade, despite the private and public benefit.

This section provides a brief introduction to the topic of data centres, outlining the recent growth, the challenges they present for energy consumption and some of the hurdles firms face in improving facility energy efficiency, such as poor metrics. The next section will detail select relevant literature from the engineering and economic perspective.

3 Literature review

This section will discuss key selected work from the mechanical engineering literature. The economic section will discuss common evaluation techniques used in areas of energy and climate change. Finally, this section will detail how economic research has modelled technology adoption in other contexts that could be relevant for studying data centres.

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[9] See http://www.thegreengrid.org/en/Global/Content/Webcast/Roundtable_EMEA_Research_April_2016

[10] See https://journal.uptimeinstitute.com/2014-data-centre-industry-survey/

3.1 Technical literature

A substantial literature exists on server cooling technology (see Ebrahimi et al., 2014). In most data centres, servers are fan-cooled with a power-hungry mechanical chiller. In a typical data centre, the energy consumption of the actual IT equipment accounts for half of the facility energy consumption. A mechanical chiller can be responsible for one third of facility energy consumption (Garimella et al., 2013). One innovation has been air-side economization ('free air' cooling) which reduces energy costs by using filtered outside air to cool servers instead of a mechanical chiller. 'Free air' cooling is popular in temperate climates, especially for 'hyper scale' facilities. Song et al. (2015) found that 'free air' cooling could reduce consumption by up to 35% compared, depending on location, weather and energy prices.

Another technology is direct liquid cooling, which pipes liquid through the computer server to remove the generated heat. Currently, the use of direct liquid cooling has typically been required for High-Performance Computing (HPC) units. However, it is suspected that typical data centres may require liquid cooling to operate effectively in the future[11]. To remove heat, Greenberg et al. (2006) note that liquid has a much higher thermal carrying capacity than air, being able to carry 3,500 times more heat. In studying a HPC unit in the USA, Sickinger et al. (2014) find that a direct liquid cooling unit (Asetek RackCDU) was easy to retrofit to the existing supercomputer. Contrary to industry concerns about liquid cooling leakage, there was no maintenance or leaks during 16 months of operation and over half of the heat emitted from the central processing unit (CPU) could be recovered. This study shows how direct liquid cooling could eliminate the need for a mechanical chiller while reducing and reusing energy. The liquid cooling system also halved the floor space required, which may factor into firm decision making.

The management of waste heat is of interest to data centres given their significant level of electricity consumption. With waste heat capture data centres could potentially meet data centre heating needs, replace power used in computer server cooling process, heat nearby premises or even convert waste heat to electricity and supply to the national

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[11] See http://www.datacenterknowledge.com/archives/2014/08/14/is-direct-liquid-cooling-making-a-comeback/

grid (Ebrahimi et al., 2014). The higher temperature of heat recovered via liquid cooling makes it the preferred means, although there is a trade-off between the quality of the waste heat collected and effectively cooling servers (Carbó et al., 2016). An Apple data centre located in Jutland, Denmark, plans to use data centre waste heat in nearby homes[12] as part of an existing district heating network which supplies 64% of homes[13]. Other work has noted the potential for data centres as part of a district heating network, but the significant capital cost of district heating systems remain a hurdle in many cases (Davies et al., 2016; IRBEA, 2016). If reusing waste heat is socially optimal, but data centre operators do not benefit from spending the extra capital to capture waste heat then it is important to design policies to help reduce this negative externality to reach the socially optimal outcome. A further discussion of policies is featured in Section 3.2. Table 1 provides a non-technical overview of certain cooling methods discussed in this paper, featuring some of the key drawbacks and benefits.

Table 1: Server Cooling Technologies

Cooling Type	Benefits	Drawbacks
Conventional Air Cooling (Mechanically chilled air is channelled through server rack.)	Cost effective Scalable Location-friendly Widely used	Mechanical chilling process is energy intensive Fan cooling is inefficient, loud, short lifespan of fans Difficult to reuse waste heat
Free Air Cooling (Outside air is channelled through server rack.)	Cost effective No mechanical chilling required Used for "hyper-scale" facilities	Not suitable at all scales Somewhat location specific Extra work required to manage humidity, particles Can cause adverse working conditions (noise, heat)
Direct Liquid Cooling (Closed loop of liquid is channelled through server rack to dissipate the heat.)	Optimal server cooling Excellent waste heat extraction – suitable for district heating Likely needed for more	More costly Not proven at "hyper scale" Not widely used Reluctance to adopt liquid

[12] See http://www.usadk.org/news/apple-establishes-one-of-the-worlds-largest-data-centres-in-denmark/
[13] See http://www.investindk.com/Clusters/Cleantech/Data-Centres

	computing power	

In summary, data centres aim to minimize their capital and operating costs. For most, this means using mechanically chilled air cooling, especially in regions with low electricity prices. For data centres in Ireland, it is estimated that energy represents up to 70% of the post-construction operating costs (Host in Ireland, 2017). For other facilities, the use of free air cooling avoids the need for a power hungry mechanical chiller. Direct liquid cooling has the potential to reduce data centre energy consumption and maximise the potential for recapturing waste heat. This section has detailed a range of data centre cooling technologies and the potential for waste heat reuse to reduce energy demand both within and outside the data centre. To date, the low commercial diffusion of liquid cooling suggests it is not yet privately optimal for firms to invest in this technology. An additional consideration is that the societal benefit of waste heat reuse is not internalised by the data centre operator. Rising energy costs might present an opportunity for companies to change.

3.2 Economic literature

Rising global energy consumption and emissions pose a serious threat to the global economy. There is a significant body of work that studies the economic consequences of climate change (Stern, 2012). To date, there is limited economic research regarding the role of data centres in the broader energy system. Economic research in this area is often interested in the effectiveness of energy-related taxes, subsidies or regulations (Alberini et al., 2016b, 2016a; Collins and Curtis, 2017). Policies in this context aim to reach a socially optimal level of energy consumption. Economic analysis is helpful as it incorporates external societal benefits, such as the wider benefit of reduced energy consumption and emissions. On the other hand, firm decisions are made based on what is privately optimal. Research has studied the benefits of other energy efficient technologies (Huang et al., 2016; Stucki and Woerter, 2016). Huang et al. (2016) find that 91% of potential improvements in the Taiwanese cement industry are cost effective and could reduce electricity consumption by 25%. Stucki and Woerter (2016) model the diffusion of energy efficient technologies for a sample of Swiss firms and find that energy taxes and non-political motivations are effective instruments. Costinot et al. (2016) take a macroeconomic perspective to climate change, noting that global GDP will fall by 0.26 percent (one sixth of total crop value) if economies fail to adapt their crops.

This paper also relates to the "energy efficiency gap" theory that energy efficient products with a positive net present value are not as widely adopted as they should be (Gerarden et al., 2015; Jaffe and Stavins, 1994). Three broad categories help to explain this paradox; market failures, model measurement error and behavioural factors. Our model of technological diffusion presents a novel example of the "energy efficiency gap", where adoption of a technology does not happen despite the fact it may be socially optimal. In studying improved energy efficiency of consumer durable appliances in the 20th century, Newell et al. (1999) found that autonomous technical change, standards and energy prices all influence the range of products on offer. The next section will discuss technology diffusion.

3.3 Technology diffusion

The case study in this paper considers how energy efficient server cooling technology could be adopted (i.e., diffuse) in the market. Diffusion is important to model as new products take time to be adopted, especially in the case of durable goods. The author is unaware of other work that has applied a model of technology diffusion to data centres. Early diffusion applications have studied mortality (Gompertz, 1825) and economic growth (Prescott, 1922). For new products, modelling market adoption helps quantify the benefit of upgrading, which could be used to design more effective policies. It is especially helpful in situations where publicly available data are limited, as is the case with data centres.

Jaffe and Stavins (1994) note that the adoption of economically superior technologies is never instant. In fact, market adoption usually approximates a sigmoid (s-shaped) curve. Technology adoption has been studied in the context of energy efficient consumer durable goods (Bass, 1967) and patterns of wind energy diffusion following policy interventions (Davies and Diaz-Rainey, 2011). Wirges et al. (2012) model the expected diffusion of electric vehicle charging points in Stuttgart over time. Baptista (1999) summarises key work in the area of induced diffusion. S-shaped diffusion features a slow initial uptake followed by rapid growth as the product becomes more widely adopted before slowing down again as the market reaches saturation. Davies and Diaz-Rainey (2011) apply the Bass model (1967) to sales data of consumer durable goods to model the expected diffusion of new technologies.

A general diffusion function is specified by Equation 1, where the change in diffusion (P) between two periods (t, t+1) depends on the speed of diffusion (b), the current penetration rate relative to saturation (P(t)) and exogenous 'external' effects, such as advertising, marketing or government interventions (a). Where this is not present, a=0.

$$\frac{\{P(t+1)-P(t)\}}{\{1-P(t)\}} = a + bP(t) \tag{1}$$

The Gompertz curve is considered a better fit than the logistic curve in some cases (Yamakawa et al., 2013). The Gompertz function (Equation 2) is an asymmetric curve, where the growth in a period (w) is related to the maximum growth rate (w_{max}) which is 1 for full market adoption, a constant (k) and the difference between the mid-point (t_m) and end point (t):

$$w = w_{max} e^{-e^{-k(t-t_m)}} \tag{2}$$

One limitation of the Gompertz curve is that it reaches its asymptotic peak at infinity. Yin et al. (2003) adjust the curve to feature a defined end-point (t_{ie}) and mid-point (t_{im}). Following Equation 3, for any given period (*i*) the proportional level of diffusion (λ_{it}) is related to the end- and mid-points of the specified horizon:

$$\lambda_{it} = \left(1 + \frac{t_{ie}-t_i}{t_{ie}-t_m}\right)\left(\frac{t_i}{t_{ie}}\right)^{\frac{t_{ie}}{(t_{ie}-t_{im})}} \tag{3}$$

This approach will be applied in the case study to forecast market adoption. It will be helpful for industry and policy stakeholders who wish to study how a new technology might be adopted. The next section introduces a case study for the Republic of Ireland, a country that has experienced a significant increase in data centre capacity in recent years.

4 The Irish data centre sector

Ireland is a popular destination for foreign direct investment. It is responsible for 14% of the global trade in ICT services in 2016 ($70 billion), more than any other individual country

(OECD, 2017). Ireland has become a popular data centre destination, with the significant sectoral electricity consumption influencing **national** electricity demand forecasts (EirGrid, 2017). This section will discuss the growth of this sector and some policy implications. A model of technology diffusion is then applied in the context of a new cooling technology for Ireland.

4.1 Economic growth and activity

If data is considered to be a "key economic asset" by the European Commission (2017b), then Ireland has a wealth of assets given the significant presence of data centres. Factors driving the location decision include a quality electricity supply, robust fibre broadband infrastructure and affordable business units (IWEA, 2015). More generally, Ireland has proven to be a popular destination for foreign direct investment (FDI), hosting nine of the top ten global ICT firms[14]. When ranking location decisions for data-driven investment, executives rated the corporate tax rate, ease of doing business and an appealing legal framework as key factors (William Fry, 2016). A survey of colocation providers by Host in Ireland, an Irish data centre industry advocacy group, found that off-island fibre connectivity, clustering of other data centres, power availability and reliability and political stability are influential factors of data centre investment in Ireland. This survey specifically noted the Dublin region due to the presence of the robust T50 fibre network. They cite evidence that colocation providers locate in Dublin due to the proximity to larger companies (such as Google, Microsoft and Amazon) whose corporate cloud services they use (Host in Ireland, 2017).

A secure electricity supply and technological readiness are key factors for data centres. Ireland ranks ranking 17th and 11th worldwide in these categories, respectively (Schwab, 2015). In a survey, 90% of respondents believe that investment in the transmission network is important for attracting foreign direct investment to Ireland (Indecon, 2015). Improving data centre energy efficiency has been a focus of the Sustainable Energy Authority of Ireland (SEAI) who formed an industry working group to "explore and address

[14] See http://www.idaireland.com/business-in-ireland/industry-sectors/ict/

common energy use and consumption issues[15]”. This produced guidance on energy efficient facility design, potential energy savings and a discussion of potential data centre retrofits.

There are concerns regarding data centres: Their constant demand profile could stress the national grid during times of peak demand. The local economic benefit of data centres has been questioned, citing the relatively low level of permanent employment (Lillington, 2016). Although data centres in Ireland cover their connection cost and pay for their energy use, the size of the market poses questions for future investment in electricity generation and grid infrastructure, especially in the Dublin region (Oireachtas, 2017). Additionally, the type of energy being used has been discussed. Many data centre operators committed to renewable energy sources pay a premium to contract for renewable energy through a ‘Guarantee of Origin’ from off-island sources. A recent estimate that cites Ireland’s annual data centre electricity demand as 1.40 TWh notes that this would comprise approximately 22% of Ireland’s current indigenous wind power resource (or 17% of the ‘imported’ renewable energy through a Guarantee of Origin (Host in Ireland, 2017).

4.2 Legislation (Brexit and GDPR)

The recent introduction of the General Data Protection Regulation (GDPR) at the EU level has significant implications for industry. Briefly, GDPR strengthens data protection legislation by protecting the privacy of all EU citizens (European Union, 2016). To comply with GDPR, companies must now receive consent from customers about storing their data and make it simple to withdraw consent. It also legislates for customers to have a right to access a copy of the personal data obtained on them, for this information to be transmitted to another data controller and for a right to be forgotten (EU GDPR Portal, 2017). GDPR legislates for every company, regardless of location, that processes the personal data of EU citizens and can impose fines for non-compliance up to 4% of global turnover. Surveyed

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[15]See http://www.seai.ie/Your_Business/Large_Energy_Users/Special_Initiatives/Special_Working_Groups /Data_Centre_Special_Working_Group_SpinI/

company executives believe that GDPR helps deliver cost savings as it harmonises regulations across the EU region (William Fry, 2016).

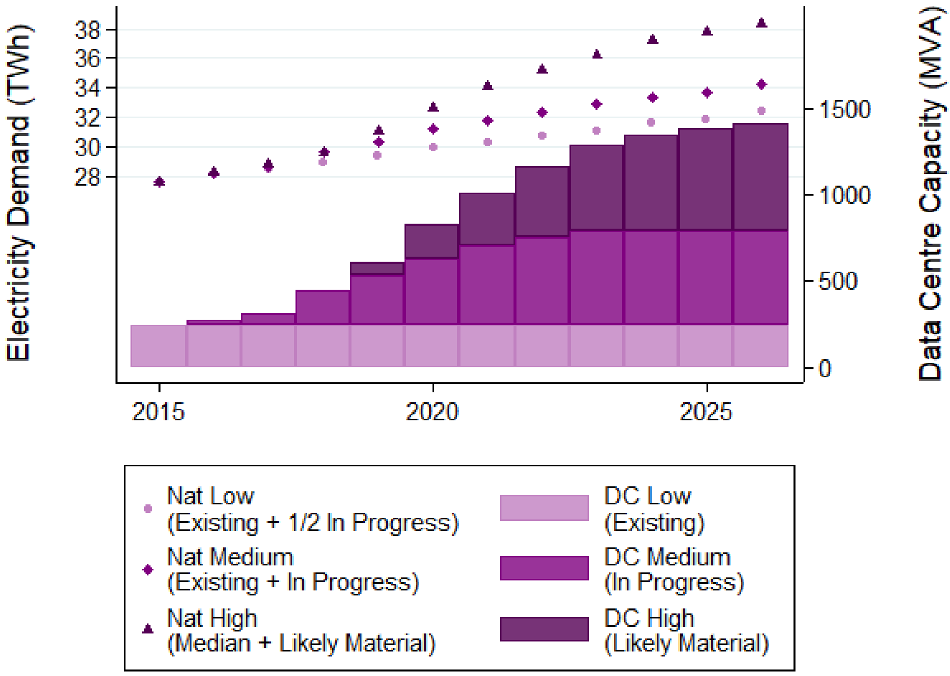
In the Republic of Ireland, a recent survey found that a majority of firms were unaware of the upcoming legislation, with a higher proportion of SMEs unaware (Data Protection Commissioner (Ireland), 2017). Paired with the impending exit of Britain from the European Union, it is important to bear in mind that UK-based data centre operators might need to relocate their data centres to the European Union to comply with data protection legislation. When considering how future Irish data centre demand may change, it is important to consider how future legislation at home and abroad may influence demand.

4.3 Challenges for energy markets

The popularity of Ireland as a data centre destination poses challenges for the electricity system. EirGrid, the Irish transmission system operator (TSO), expects new data centre capacity to drive three quarters of the national growth in electricity demand over the next decade (Oireachtas, 2017). In 2016, data centres in the Republic of Ireland had an installed capacity of approximately 250 MVA (EirGrid, 2017). It is estimated that an additional 540 MVA is in progress with further enquiries of an additional 640 MVA by 2026. Figure 2 illustrates how national electricity demand forecasts ("Nat" points, left hand y-axis) are influenced by different levels of data centre installed capacity ("DC" stacked bars, right hand y-axis). In order (from smallest to largest), the demand forecasts in Figure 2 reflect the following scenarios:

- Low: All existing data centre capacity and half of all in-progress enquiries
- Median: All existing data centre capacity and all in-progress enquiries
- High: All existing, in-progress and likely material enquiries

Figure 2 – Projected Electricity Demand and Data Centre Installed Capacity (Republic of Ireland)



Source: EirGrid (2017)

4.4 Climate change implications

A growing data centre sector poses a risk to national emissions reduction targets. Ireland has committed to reduce emissions in 2030 by 30% relative to 2005 emissions levels (EC, 2016). The Environmental Protection Agency (EPA) uses energy balance data to estimate greenhouse gas (GHG) emissions for Ireland, following UNFCCC guidelines (Table 2). Irish GHG emissions in 2015 were estimated at 59.88 million tonnes of carbon dioxide equivalent (Mt CO_2eq), a 3.7% increase on 2014. This trend is attributed to increased economic activity. Currently, Ireland is not on track to achieve an agreed 20% reduction in non-Emissions Trading Scheme (ETS)[16] emissions, relative to 2005 levels, by 2020. To achieve compliance, Ireland must improve efforts in this space or face fines. Alternatively, they may be able to buy emissions credits from EU member states who overachieve their target. Although the price per tonne of abatement is not yet certain, it is believed that this could range from €80-140 million for falling short of emissions reduction targets. However, there could be

[16] Non-ETS sectors include agriculture, transport, built environment, waste, non-energy intensive industry.

additional costs associated with failure to achieve an agreed amount of renewable energy generation[17].

Table 2 – Ireland Emissions (By Sector)

	2015 (Mt CO_2eq)	Proportion (%)
Overall Emissions	59.878	-
Energy Industries	11.803	19.71
Industrial Processes	1.993	3.33
Manufacturing Combustion	4.549	7.60
Agriculture	19.807	33.08
Transport	11.827	19.75
Residential	6.041	10.09
Waste	0.974	1.63
Other (Commercial & Public Services, F-Gases)	2.884	4.82

Source: (EPA, 2017a)

Rising data centre demand may impact future emissions. The EPA notes that in 2015, the entire public electricity and heat production for Ireland generated 11,328 million tons of CO_2 equivalent (Mt CO_2eq), almost 19% of annual national emissions. For data centres, EirGrid (2017) estimates that approximately 250 MVA installed capacity of data centres consumes roughly 7.5% of the national electricity demand (~2 TWh out of 27 TWh). We return to this topic in Section 6.4. The EPA forecasts two scenarios of Ireland's 2035 CO_2 emissions. The first assumes Ireland implements no change in energy-related policies beyond 2015 ("With Existing Measures"). The second assumes that Ireland implements 2020 policy changes as per the National Renewable Energy Action Plan (NREAP) and the National Energy Efficiency Action Plan (NEEAP) ("With Additional Measures") (EPA, 2017b).

Macroeconomic projections rely on the ESRI COSMO model to derive equations for demand by fuel and sector[18]. Under the "With Additional Measures" scenario, overall 2030

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[17] See https://www.rte.ie/eile/brainstorm/2017/1124/922516-missing-climate-and-energy-targets-will-cost-ireland-millions/

[18] See https://www.esri.ie/projects/modelling-the-irish-economy/

emissions are projected to be 3.6% higher than in 2016 (a 6.4% increase from 2020 to 2030) and emissions from electricity and heat production are estimated to comprise 17% of total emissions in 2030 (a 21.6% increase from 2020 to 2030). Since electricity generation is covered under the Emissions Trading Scheme (ETS) it does not feature in 2020 national emissions reduction targets. At the EU level, it is expected that ETS-sectors will need to reduce their emissions by 43% compared to 2005 levels by 2030, with national annual targets yet to be determined (EPA, 2017b). Ireland is not on track to meet upcoming emissions reduction targets. The rising demand for data centres could present an additional barrier. The next section sets up a case study for the adoption of liquid server cooling for the Irish market.

5 Case study for the Irish electricity sector

5.1 Assumptions

In this section, we model technological diffusion for how new liquid cooling technology might lower the energy demand of the Irish data centre sector and how this may impact national electricity demand. Given the lack of public data, assumptions are needed regarding the composition of data centres and the rate at which they upgrade their facility:

1. The Irish data centre market is comprised of homogenous facilities that all use conventional mechanical cooling.
2. A form of direct liquid cooling for computer server cooling is adopted. This is chosen for three reasons: Firstly, rising global demand for data will require denser computer servers. Secondly, liquid cooling is adopted due to the increased server density. Thirdly, increasing energy and climate awareness will spur interest in technologies that help reduce energy consumption and can effectively repurpose waste heat.
3. The technology is assumed to provide a 33% reduction in data centre electricity demand (following Garimella et al. (2013)). We assume that waste heat capture is present (but not quantified) as the commercial viability of liquid cooling relies on waste heat recapture, especially at large scale (Garimella et al., 2013).

5.2 Data

The initial data used in this work is national data centre capacity information from EirGrid. Future work in this space aims to better inform our assumptions using real plant-level data. In order to estimate sectoral electricity consumption the values for installed capacity (MW) are converted into units of energy (MWh)[19] and multiplied by the number of days and hours, assuming a capacity factor of 0.75 (used previously by IWEA (2015)). It is assumed in most cases that data centres adopt the new technology following the market diffusion pattern (discussed in Section 5.4).

5.3 Scenarios

The reduction in electricity demand depends on the share of the market that adopts and when this occurs. To address the former, we consider four potential scenarios using a simple taxonomy (Table 3). Two types of data centre are considered: Those in operation before 2017 ("Existing") and those in the connection process[20] ("New"). Data centres choose whether to use traditional mechanical air cooling (using a vapour compression cycle as opposed to outside ambient air) ("M") or the new liquid cooling ("L").

Table 3 – Taxonomy of adoption scenarios

		Existing data centres (E)	
		Liquid (L)	Mechanical Air Cooled (M)
New data centres (N)	Liquid (L)	N_L, E_L	N_L, E_M
	Mechanical Air Cooled (M)	N_M, E_L	N_M, E_M

1. Business as Usual (N_M, E_M): Liquid cooling is not adopted by any plant. Consumption in this case is assumed to match the projection provided by EirGrid.

[19] See http://www.aweo.org/windunits.html

[20] As per EirGrid (2017) median scenario of installed data centre capacity

2. New Only Diffusion (N_L, E_M): In this scenario, only the new data centres will adopt liquid cooling as the existing stock of data centres do not adopt the technology.
3. All Diffusion (N_L,E_L): Both existing and new data centres adopt liquid cooling.
4. Stock Only Diffusion (N_M, S_L): In this scenario, only the existing stock of data centres adopt liquid cooling.

Scenario 4 is omitted as it is unlikely that new data centres would not adopt the new technology while existing facilities do. In Scenario 2 it is also assumed that new data centres adopt the new cooling technology when they open, instead of following the market adoption pattern (discussed in the next section). Three situations will be analysed:

1. Business as usual (BAU: N_{NL}, S_{NL})
2. New Only Diffusion (ND: N_L, S_{NL})
3. All diffusion (AD: N_L,S_L)

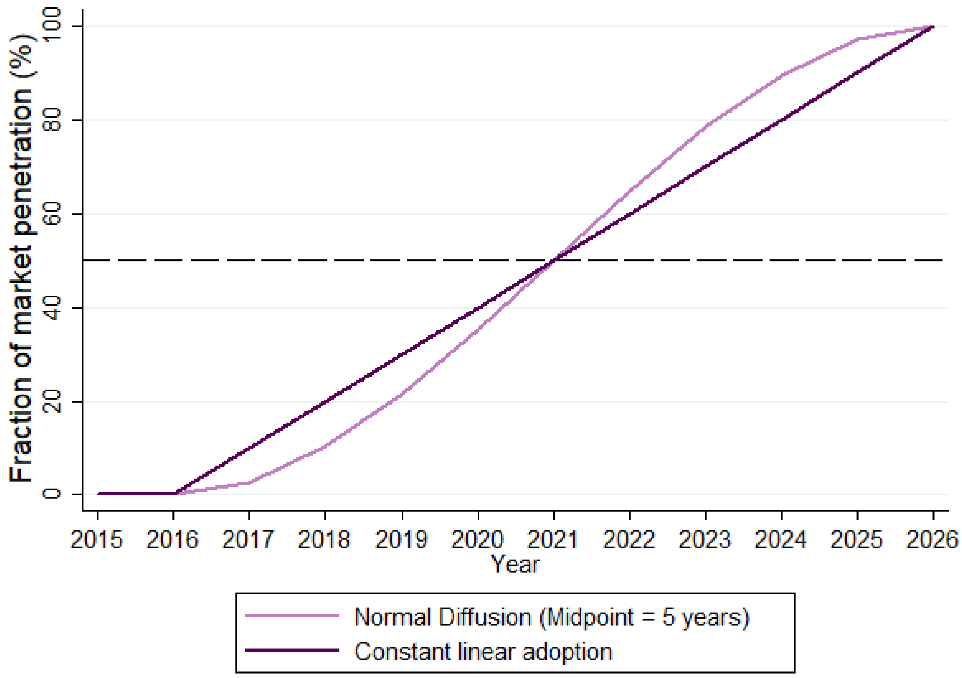
5.4 A model of technology diffusion

The rate of diffusion determines how quickly the new technology is adopted and energy is saved each year. We follow Yin et al. (2003) and assume full market adoption by 2026[21]. The point at which half of the market has adopted the new technology is set at 2021, reflecting a symmetric adoption pattern (See Appendix 1 for a more detailed discussion).

An 's-shaped' diffusion curve is appealing as it is more indicative of market behaviour than the unrealistic assumption of a constant adoption rate in each period. Initial adoption is slow. Following this, growth increases as other firms observe the technology and decide that it is viable. As the technology approaches full market adoption, growth slows due to saturation. The 's-shaped' line in Figure 3 illustrates the adoption pattern for our diffusion pattern that takes five years (from 2017) for the new liquid cooling to reach half market penetration. Results are presented using this rate.

Figure 3 – Rate of diffusion

[21] Future versions of this paper will hope to address this limitation by generating results for a subset of the entire population of data centres believed to be the likeliest candidate for liquid cooling.



6 Results – Electricity Demand

As discussed in Section 5.2, our sample uses publicly available data from EirGrid, the Irish Transmission System Operator (TSO), who provide annual forecasts of data centre capacity (in MVA) and national electricity demand (in TWh). In addition to the three EirGrid scenarios (Low, Medium, High), two diffusion scenarios are derived from the EirGrid Medium data:

1. Business as Usual: Identical to the EirGrid data for sectoral growth and national consumption (BAU_{Low}, BAU_{Med} and BAU_{High}).
2. New Only Diffusion: Upcoming data centres adopt automatically.
3. All Diffusion: Every data centre follows the diffusion pattern.

6.1 Sectoral demand

Table 4 and Figure 4 estimate sectoral electricity demand. In every case, it is assumed that data centres have a capacity factor of 0.75. In comparing the BAU_{MED} scenario to the two diffusion scenarios (ND, AD), we note the consumption of data centres would be 22.8% lower in the “New only diffusion” diffusion (ND) scenario by 2026. This reduction increases to 33.3% in the “All diffusion” scenario (AD). This result is largely driven by the assumption that the new technology will reduce data centre energy consumption by a third.

Relative to the estimated electricity consumption of the EirGrid Medium scenario, the ND and scenarios would lower data centre consumption over the twelve-year period by

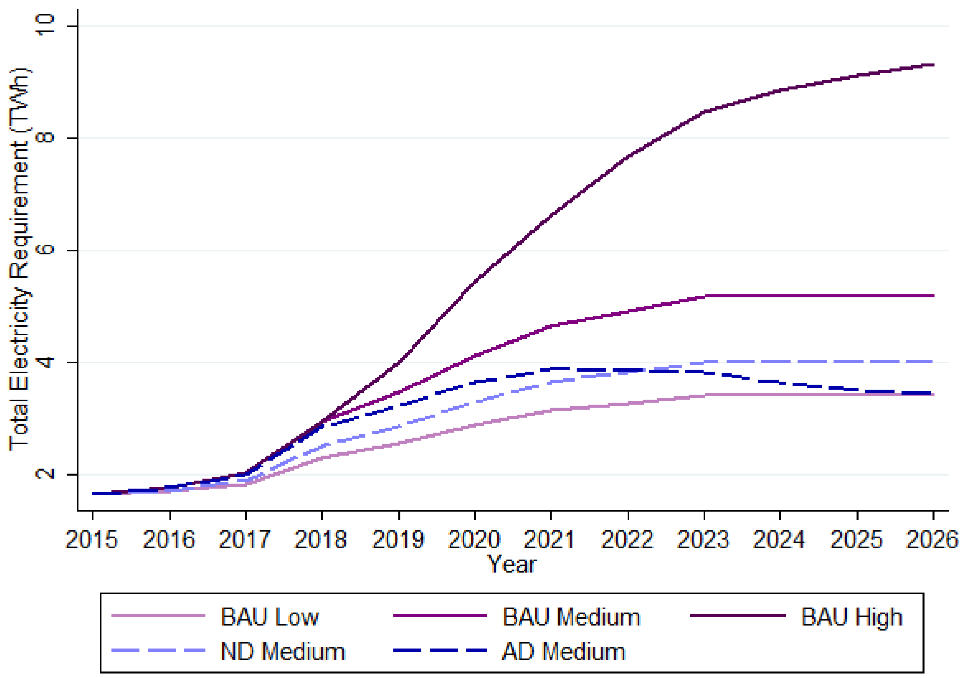
19.17% and 19.44%, respectively. In Figure 4 the faster initial reduction in demand is delivered by new data centres opening and adopting the new technology. However, the addition of new data centres stagnates in 2023, and the AD scenario makes greater gains as the entire market adopts the new technology. By 2026, we note that both scenarios are below the EirGrid Medium estimate, with the AD scenario almost equalling the EirGrid Low scenario, where only half of the new data centres already in the connection process come online.

Table 4 – Data centre sector electricity demand

	BAU			ND	AD
	LOW	MED	HIGH	MED	MED
2015	1.64	1.64	1.64	1.64	1.64
2016	1.70	1.77	1.77	1.73	1.77
2017	1.83	2.03	2.03	1.90	2.01
2018	2.29	2.95	2.95	2.52	2.85
2019	2.56	3.48	4.00	2.87	3.23
2020	2.89	4.13	5.45	3.31	3.65
2021	3.15	4.66	6.63	3.66	3.88
2022	3.28	4.92	7.68	3.83	3.86
2023	3.41	5.19	8.47	4.01	3.83
2024	3.41	5.19	8.86	4.01	3.64
2025	3.41	5.19	9.13	4.01	3.50
2026	3.41	5.19	9.32	4.01	3.46

***Note: Values are in units of TWh. Assumes a data centre capacity factor of 0.75. Source: EirGrid data and author's calculations.**

Figure 4 – Data centre sector electricity consumption



***Note: Assumes a data centre capacity factor of 0.75. Source: EirGrid data and author's calculations.**

6.2 National demand

Table 5 and Figure 5 detail national electricity demand, with the three BAU scenarios where no technology diffusion occurs (solid lines). These results mirror EirGrid (2017). For both diffusion scenarios (light blue ND line, dark blue AD line), national electricity demand is deflated according to Equation 4, adjusted by subtracting the share of the diffusion scenario (ND or AD, respectively) data centre consumption of BAU_{MED} national consumption from the fraction of BAU_{MED} data centre consumption out of the national amount. This is necessary due to lower data centre energy consumption resulting in a lower level of national consumption. In 2026, the ND scenario reduces national electricity consumption by 3.48% relative to BAU_{MED}, while the AD scenario would save 5.08%. Over the entire twelve-year period, this translates to a reduction of 2.40% and 2.43% for ND and AD scenarios, respectively.

$$NatDem_{AD,ND} = NatDem_{BAU\_MED} * \left[1 - \left(\frac{DC\ Cons_{BAU_{MED}}}{NatDem_{BAU_{MED}}} - \frac{DC\ Cons_{AD,ND_{MED}}}{NatDem_{BAU_{MED}}}\right)\right] \qquad (4)$$

Key:

NatDem = National electricity demand where adoption of liquid cooling occurs

DC Cons = Share of national electricity consumption attributable to data centres

BAU_{MED} = EirGrid medium forecast of national electricity demand

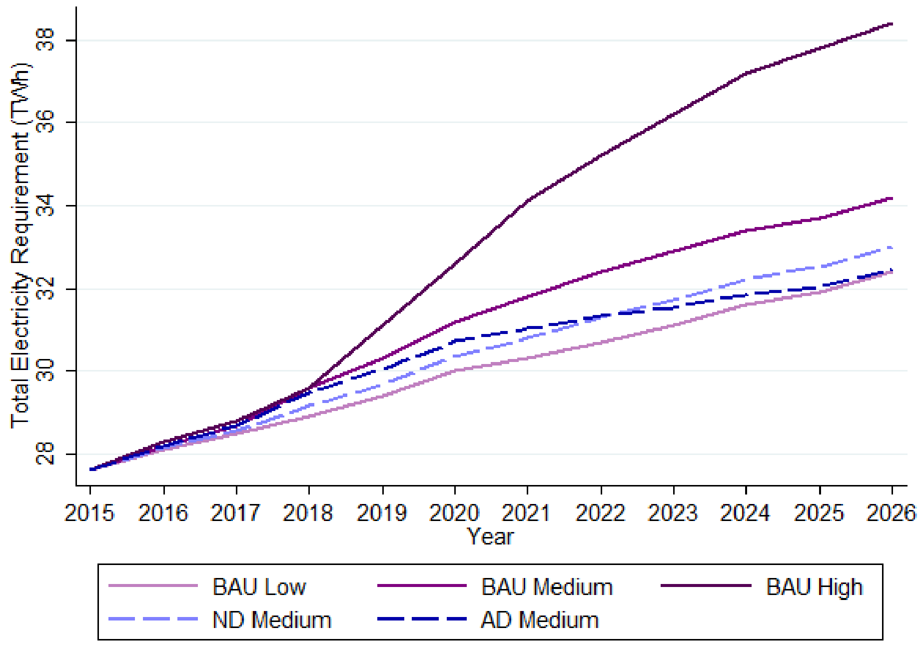
AD = All data centres adopt liquid cooling; ND = Only new build of data centres adopt liquid cooling

Table 5 – National Electricity Demand

	BAU			ND	AD
	LOW	MED	HIGH	MED**	MED**
2015	27.6	27.6	27.6	27.60	27.60
2016	28.1	28.2	28.3	28.16	28.20
2017	28.5	28.7	28.8	28.57	28.68
2018	28.9	29.6	29.6	29.16	29.50
2019	29.4	30.3	31.1	29.69	30.05
2020	30	31.2	32.6	30.37	30.71
2021	30.3	31.8	34.1	30.79	31.02
2022	30.7	32.4	35.2	31.30	31.33
2023	31.1	32.9	36.2	31.72	31.54
2024	31.6	33.4	37.2	32.22	31.85
2025	31.9	33.7	37.8	32.52	32.02
2026	32.4	34.2	38.4	33.02	32.47

***Note: Values are in units of TWh. Assumes a data centre capacity factor of 0.75. **Note: ND_{MED}, AD_{MED} based on deflated value of BAU_{MED} to reflect lower data centre consumption. Source: EirGrid data and author's calculations.**

Figure 5 – National energy consumption (All scenarios)



***Note: Assumes a data centre capacity factor of 0.75. Source: EirGrid data and author's calculations.**

6.3 Data centre electricity demand as share of national

Table 6 highlights the national share of electricity consumption attributable to data centres. In each diffusion case we see data centres comprise a lower fraction relative to the BAU_{MED} scenario. For the ND scenario, the share is over three percent lower than in the BAU_{MED}. The reduction is even greater for the AD scenario, with data centres comprising only 10% of the national electricity demand. This result holds even if we obtain the share of data centre consumption as a fraction of the **deflated** national electricity consumption (Denoted by ** suffix in in Table 6. Following Equation 4).

Table 6 – Data Centre Share of National Electricity Demand

	BAU			ND	AD	ND	AD
	LOW	MED	HIGH	MED	MED	MED**	MED**
2015	5.95	5.95	5.95	5.95	5.95	5.95	5.95
2016	6.08	6.29	6.27	6.14	6.29	6.14	6.29
2017	6.45	7.1	7.07	6.64	7.03	6.67	7.04
2018	7.96	9.99	9.99	8.51	9.64	8.64	9.68
2019	8.72	11.4	12.8	9.47	10.6	9.66	10.7
2020	9.64	13.2	16.7	10.6	11.7	10.89	11.9
2021	10.4	14.6	19.4	11.5	12.2	11.88	12.5
2022	10.7	15.2	21.8	11.83	11.9	12.24	12.3
2023	10.9	15.7	23.4	12.18	11.6	12.64	12.1
2024	10.8	15.5	23.8	12	10.9	12.44	11.4
2025	10.7	15.4	24.1	11.89	10.4	12.32	10.9
2026	10.5	15.1	24.3	11.72	10.1	12.14	10.6

***Note: Values are in percent (%). Assumes a data centre capacity factor of 0.75. **Note: ND_{MED}, AD_{MED} based on deflated value of BAU_{MED} to reflect lower data centre consumption. Source: EirGrid data and author's calculations.**

Results presented serve to highlight the potential impact of efficiencies in data centre energy consumption. Reductions in sectoral energy consumption will translate to a fall in national electricity consumption[22]. In the next section, we attempt to quantify the emissions-related savings associated with reductions in data centre electricity demand,

[22] A more conservative set of results which assume that 'hyper scale' data centres are excluded from the analysis is planned for future versions of this paper.

considered to be one of the societal benefits of reductions in data centre energy consumption.

6.4 Results – Carbon Dioxide Emissions

There are significant emissions associated with electricity generation and consumption. This section provides a preliminary estimate of the carbon emissions that would be saved under each scenario[23]. The International Energy Agency (IEA) publishes emissions factors for individual countries, which relate the level of carbon dioxide (CO_2) emissions to the quantity of energy consumed in a country. However, Brander et al. (2011) note that the IEA reports a composite electricity and heat emissions factor, which might not reflect the actual value of electricity emissions. For data centres whose main energy source is electricity, the emissions factor used should be adjusted to reflect electricity consumption. Table 7 presents emissions factors for Ireland based on 2010 energy quantities, accounting for transmission and distribution losses, finding a 7% difference between the IEA composite emissions factor and the constructed electricity specific factor by Brander et al. (2011).

Table 7 – Electricity specific emissions factors

	$kgCO_2/kWh$	
Electricity-specific generated emissions factor	0.5212	(1)
IEA composite electricity/heat factor	0.4862	(2)
Difference	0.0350 (7.2%)	(1-2)
Electricity transmission & distribution loss emissions factor	0.0449	(3)
Electricity consumed emissions factor	0.5661	(1+3)

Source: Brander et al. (2011) data for Ireland.

The electricity-specific emissions factor (Brander et al., 2011) is applied to the electricity consumption in each scenario to quantify the abated emissions. Table 8 lists the level of expected CO2 emissions for each of our scenarios. Over the entire period, emissions would be 19.2% lower for the 'New Diffusion' scenario and 19.4% lower for the 'All Diffusion

[23] It is anticipated that this section will be superseded when analysis using the power systems model is conducted in later versions.

scenario. Compared with the latest EPA estimates of Irish emissions, we find that data centres would be responsible for 1.5% of 2015 national emissions (59.878 $MtCO_2$) and 7.9% of emissions in the 'Energy Generation' sector (11.803 $MtCO_2$).

By 2026, emissions for the AD scenario would be 3.27% of 2015 national emissions and 16.6% of the 2015 'Energy Generation' sector. It is important to view these results as illustrative given that results are sensitive to the emissions factor, which is likely to change over time as the generation mix for Ireland changes.

Table 8 – Estimates of sectoral CO2 emissions

	BAU			ND	AD
	LOW	MED	HIGH	MED	MED
2015	.929	.929	.929	0.929	0.929
2016	.966	1.00	1.00	0.979	1.004
2017	1.04	1.15	1.15	1.078	1.142
2018	1.30	1.67	1.67	1.425	1.615
2019	1.45	1.97	2.26	1.623	1.828
2020	1.63	2.34	3.08	1.871	2.067
2021	1.78	2.64	3.75	2.07	2.2
2022	1.85	2.78	4.35	2.169	2.186
2023	1.93	2.93	4.79	2.268	2.169
2024	1.93	2.93	5.02	2.268	2.06
2025	1.93	2.93	5.16	2.268	1.985
2026	1.93	2.93	5.28	2.268	1.958
Total	18.67	26.20	38.44	21.217	21.14

***Note: Values are in units of million tonnes of CO2 equivalent (Mt CO_2eq), based on electricity demand in terms of TWh. Assumes a data centre capacity factor of 0.75.**

This paper draws a direct connection between reductions in data centre electricity consumption and the resulting reduced emissions from electricity generation. If electricity generation becomes less carbon intensive in the future, a lower emissions factor would reduce the potential savings achieved by reducing data centre energy consumption. For this reason, the estimates here should be considered an upper bound on the potential savings. In future research, this work will benefit from deeper analysis using a power systems model. Additional emissions that would be avoided by using recaptured waste heat is something that will also be addressed in future research.

7 Discussion

This paper presents an overview of the economic importance of data centres and the wide-ranging implications an increase in data centre capacity might have for future energy consumption. Data centres are an example of a rapidly evolving technology posing a challenge for firms and policymakers, especially with decisions that often feature capital investment. Increasing data centre capacity poses a challenge for future energy demand, transmission systems and emissions. Efficiencies in this space ultimately depend on the rate at which firms adopt any new, more energy efficient technologies. To account for this, the work in this paper applies an economic model of technology adoption. When evaluating technologies that improve data centre energy efficiency, it may also be important to consider internalising externalities such as carbon emissions and societal benefits of increasing efficiency when conducting a cost benefit analysis. This paper provides a basic assessment of how this might impact the level of carbon dioxide emissions associated with electricity generation.

The key finding in this paper is that data centres are expected to greatly influence electricity demand in Ireland. We highlight the savings that could be made over the next decade if a new, energy efficient technology was available using a model of technology diffusion, which represents a more realistic adoption curve than assuming a constant rate of adoption. Using this method, reductions in sectoral and national energy demand and carbon dioxide emissions are estimated. Estimates of the twelve-year reduction in national electricity demand from 2015-2026 range from 2.40% and 2.43% for New Only diffusion (ND) and All Diffuse (AD) scenarios, respectively. This paper also provides background literature from both the engineering and economic perspective to inform readers of key global trends in data centre cooling in addition to detailing the global industry and policy context.

Certain topics are beyond the scope of this study. Although future market trends cannot be predicted, technological innovations are expected. Advancements in energy generation, transmission and interconnection will also matter. As mentioned earlier, legislation and political events may impact the data centre sector. Other economic considerations which might influence data centre investments, such as local land usage and the presence of foreign direct investment, have not been considered.

7.1 Future work

This paper is the first component of a multi-stage research project aiming to study the wider economic effects of data centres. The next component will consider wider Irish energy sector consequences of a reduction in data centre energy demand using a power systems model to estimate energy price and emissions. It is envisioned that later components will treat any changes in energy prices as an economic shock which can be used to estimate changes in macroeconomic variables through a structural econometric model of the Irish economy that is currently used for medium-term projections and policy analysis.

Another likely extension to this work in the future is to quantify the additional benefit of data centre waste heat reuse. Section 6 considered the change in sectoral demand if data centres adopted liquid cooling according to the market adoption curve. Liquid cooling is more suitable for waste heat recuperation, collecting exhaust heat from servers to heat the data centre or be used as part of a district heating system. However, the extra capital cost and additional private and social benefits should be considered as part of any analysis.

Finally, future work will look to extend the existing analysis by relaxing assumptions about the share of the entire market that is expected to adopt liquid cooling. This may be helpful to present results where a certain type of data centre (e.g. hyperscale) may not be interested in upgrading their facility to feature liquid cooling.

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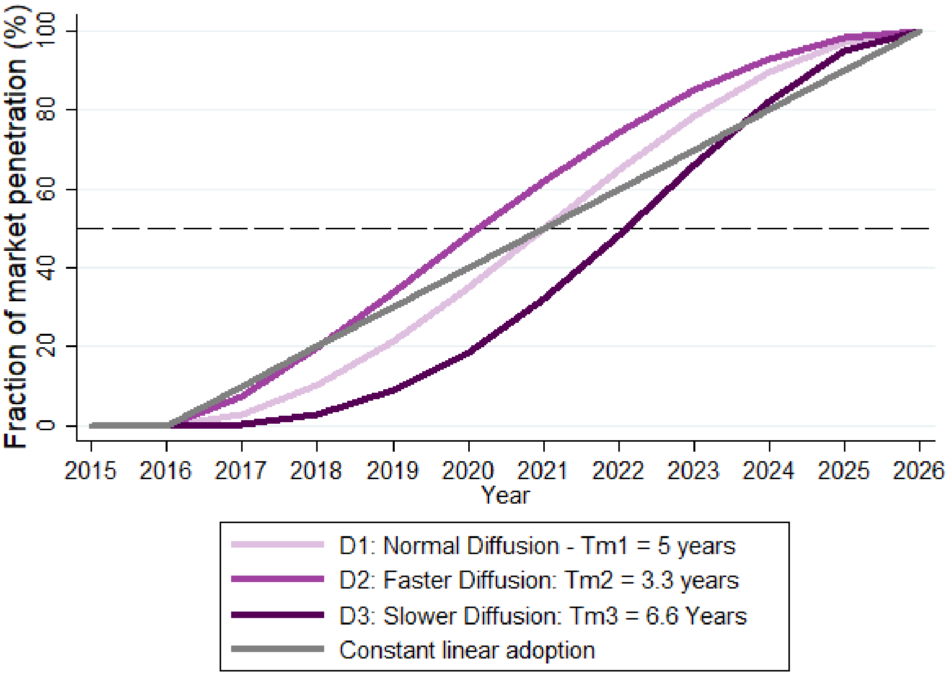
9 Appendix 1: Alternative rate of diffusion

Results in this paper use a specific rate of market adoption, where half of market saturation occurs exactly halfway through the period of analysis, resulting in a symmetric adoption curve where the entire market adopts the new technology. An 's-shaped' diffusion curve is more reflective of market adoption patterns than assuming an unrealistic constant adoption rate.

One common feature is the slow initial level of adoption. Following this, growth increases as other firms observe that the technology is viable. Adoption slows as the market becomes saturated. Alternative assumptions can be made regarding this period which could skew market adoption to be earlier or later. Figure 6 illustrates a range of adoption patterns, with the point at which market adoption is at 50% reflected by the dashed line.

Figure 6 – Alternative rates of diffusion



Normal diffusion (D1) takes five years beginning in 2017 for the new technology to reach half market penetration. This is the smoothest growth pattern. Faster diffusion (D2) features faster initial adoption followed by slower subsequent market penetration. Slow diffusion (D3) is skewed to the right, with slower initial adoption that increases quickly towards the end of the horizon. The rate chosen influences the energy savings in each period. Main results are presented using the normal diffusion rate (D1). In this case, the chosen diffusion rate expects the entire sample to have adopted the technology by 2026.