

Systems Modelling of New Media Services¹

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Abstract—Energy consumption has long been identified as a major sustainability issue through its contribution to global greenhouse gas emissions and the limited supply of non-renewable resources. Current research on energy consumption for online media distribution identifies server operations as a main contributor. Based on work with an online news-publishing group we explore the system dynamics of energy consumption in the distribution of media. Building on concepts developed in a causal loop model based on previous work we present a system dynamics model of energy consumption for online digital media distribution and explore a number of scenarios. According to the model we have developed the future dynamics of energy use for the delivery of media services are apparently bounded by three factors; i) the overall energy efficiencies deliverable by the ICT supply chain into the data centre, ii) the overall media “richness” of content and how that is effected by investment, mutualisation and content synergy, and iii) growth in the user base. Questions arising from the use of the abstractions for richness, synergy, and mutualisation in the modelling have opened up a profitable area of further work to explore.

Keywords—strategy, sustainability, media services, news media, markets, substitutes, diffusion models

1 INTRODUCTION

The SYMPACT project is a partnership between the University of Bristol, Guardian News and Media (GNM) and the University of Surrey Centre for Environmental Strategy and its purpose is to develop models of different future scenarios as to how the news industry might look as a result of digital technology innovations with a view to informing sustainability strategies. The modelling approach adopted by the project intends to integrate environmental life-cycle assessment (LCA) techniques into systems approaches, allowing the combination of quantitative energy and emissions analyses with more speculative models of technological and behavioural change, such as models of the shift from paper to online news reading or the uptake of electronic reader devices.

Digital technology is transforming the news, media and publishing industries, through the movement of activity to the web accessed both through PC and 3G phone, specialised eReader devices such as the Kindle and iPad, and the flexibility that digital printing offers over traditional offset approaches. This transformation is coming at a time of increased concern over energy availability and greenhouse gas emissions. Will the transformation decrease or increase the energy requirements of the news and media industry? Can the industry embed an understanding

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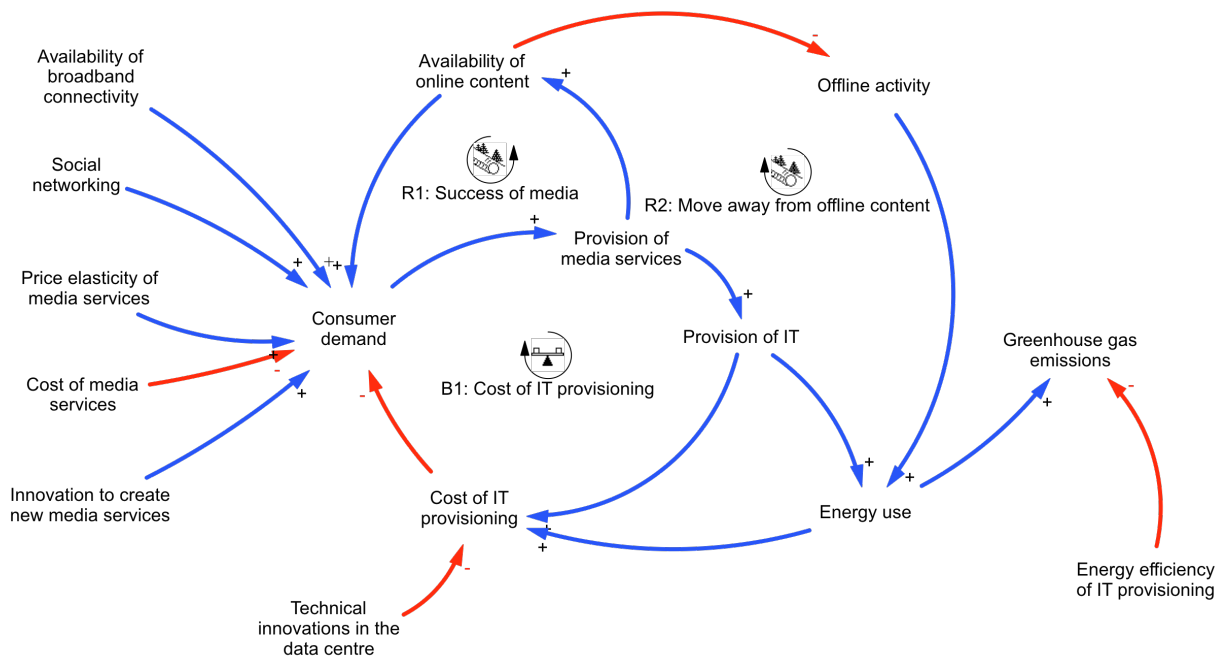
of the future energy/climate implications in the strategic decisions it makes?

The SYMPACT project aims to support this understanding by considering a number of questions; what is the environmental impact of both print and online media? How will changes in technology alter this impact over time? How is digital technology changing customer behaviour now, and how might this happen in the future? What new business models do technological advances open up, and how will they affect the environmental impact? How will environmental factors, such as carbon pricing, act as business and behavioural drivers within this system? Beyond energy and climate, what other sustainability implications might this transformation have?

This paper concentrates on the problem of modelling the dynamics of energy use associated with the future development of on-line delivery of news media content.

2 ANALYSIS OF ENERGY USE FOR DOWNLOADED DATA

Previous work by (Preist and Shabajee, 2010) presented an analysis of the potential demand for downloaded data from the *global* aggregate of online media services. In addition to a quantitative estimate of energy use as $\sim 1.2 \times 10^{12}$ Watts to support current use at current levels of efficiency the paper goes on to discuss energy efficiency trends and likely new applications that will increase bandwidth requirements, From this paper an initial causal loop model was developed using an hermeneutical approach based on ideas drawn from (Hindle, 2007).



Model 1. Initial causal loop model of media services energy demand

The model generated suggests that growth in energy use is reinforced by the simultaneous switch from consuming media via traditional printed routes (i.e. offline activity) and the growth in consumer demand created by the availability of online content. This growth is balanced by technical innovations in the data centre itself and the wider overall energy efficiencies achievable in IT provisioning generally.

The preliminary causal loop model was used to inform the initial system dynamics model for the SYMPACT project in order to establish a quantitative model to describe current energy use and CO₂ for the delivery of digital media services. The development of this model and the research questions it raises are the main subject of this paper. A key requirement for the SYMPACT project is the development of a capability to model new service uptake to understand likely energy use and greenhouse gas (GHG) emissions from the data centres, networks and access devices involved. Dynamic modelling will provide one of the tools within SYMPACT to help formulate strategy as they move towards greater delivery of online services. Of critical interest is the interaction between different types of online services which is discussed in detail in §4.3. In §3 we review previous work modelling uptake of telecommunications services and the relevance of diffusion models to our work.

3 REVIEW

An important question for the development of suitable models for SYMPACT project is the relevance of diffusion models (Bass, 1969) to understanding substitution between competing service types in the market (Porter, 1979, Porter, 2008). Whilst other work in the SYMPACT project is looking at the migration from print to digital media the substitutes of focus in this paper concern the different ways in which online media can be delivered.

Previous system dynamics modelling of new telecoms services uptake provides a useful analogue for internet-delivered media services and a starting point for understanding the issues raised by the SYMPACT project requirements. Early work at BT Laboratories (Barnes, Burton, Hawker and Lyons, 1994) was based on market diffusion models and they explicitly modelled migration from paper to electronic information. However, this was relatively simplistic and the uptake rate was determined purely by access to the necessary technology. This uptake rate then drove further user behaviours relating to telework and meetings. Of more relevance to SYMPACT was the fact that BT Laboratories viewed substitutes (e.g. video, voice, email, data, fax) as aligned within different business sectors and resorted to analytical models of their relative dynamics. This reflects the fact that at the time the technologies used to deliver these different services were quite different, the Internet had yet to exert its converging influence.

However, the online media market is significantly more complex in that the service types are not truly independent substitutes, for example an embedded link to a video on YouTube within a twitter feed uses one type of media to promote another. There is thus the possibility of considerable synergy, particularly by third parties, through the “*mashups*” enabled by Web 2.0 technology (Murugesan, 2007) that could lead to incredibly rich services emerging that are not entirely within the control of a single online media provider but that still have significant impact on data centre energy use and emissions. This notion of rich-ness and synergy is discussed further in §4.3.

Whilst further work at BT Laboratories (Lyons, Burton, Egan, Lynch and Skelton, 1997) showed an increased sophistication towards accurate prediction of market volumes and introduced the use of the Non Uniform Influence (NUI) model (Arthur, 2006, Easingwood, 1988) to improve on deficiencies of the Bass model the results did not warrant their inclusion in the SYMPACT modelling reported here. It remains unclear how diffusion models could be used to explore scenarios where i) the system is open with respect to population i.e. “Potential Adopters” in the case of an online media service provider could be some unknown percentage of the global online community, and ii) there is no clear distinction between the different service types e.g. video

does not substitute text, but enhances it.

It was decided that having rejected the use of diffusion models, and NUI, until the substitution question could be suitably resolved there was also little need to pursue alternative diffusion modelling approaches such as agent based models (ABM), analytical models, or discrete event models (DEM) (Rahmandad and Sterman, 2008, Borshchev, 2004).

4 MEDIA UPTAKE MODEL

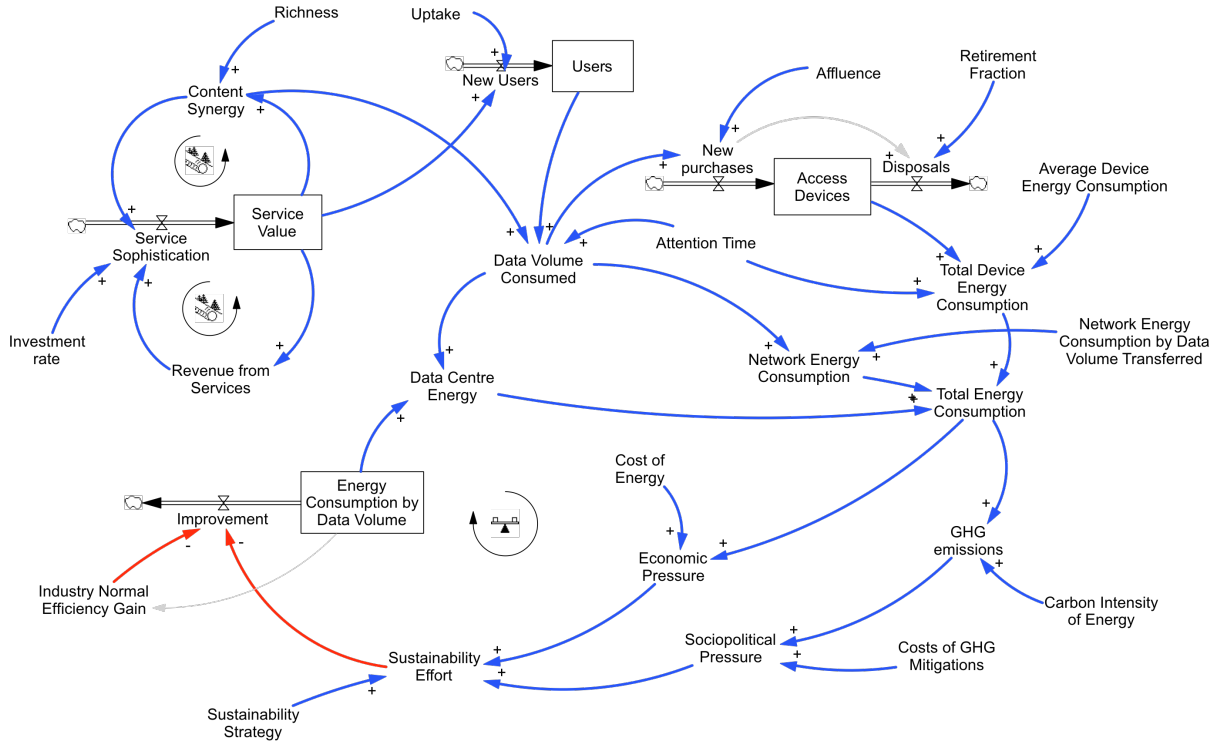
Current research on global energy consumption by digital media focuses on quantifying three main processes: the energy consumed by servers in data centres, the distribution network and the end user devices (Preist and Shabajee, 2010). According to (Taylor and Koomey, 2008) and (Preist and Shabajee, 2010) the energy consumption in the distribution and consumption of content through the internet is to first order proportional to the amount of data transferred which directly depends on the number of users and the average amount of data each user downloads. Thus, the starting point for development of Model 2 was the variable <data volume consumed> which provides the driver for energy consumed, and consequently GHG, in serving content, delivering content across the Internet and in driving demand for new <access devices> to present the content to <users>. In order to limit the complexity of the model we have focused on investigating the dynamics of energy consumption from the point of view of a media service provider. Hence, for the purpose of the analysis presented in this paper, we do not model emissions generated in the manufacture of servers and devices

Having understood the potential complexity arising from the idea of <content synergy> it was decided that this was an area of further work and that for the purposes of this model an abstraction was required. We introduced the concept of service <Richness> in order to parameterise the abstraction and make it dimensionally correct (Coyle and Exelby, 2000) so that we could explore limits of systems behaviour scenarios before having an adequate micro-structural account of content synergy in place. This is discussed further in §4.3 below and in the discussion §6.

4.1 Total Energy

In our model these factors aggregate in one variable, the <Total Energy Consumption>. The power draw from the data centres is represented by the variable <Data Centre Energy>.

Our model introduces several abstractions that simplify the complex mechanisms in a media service provider's digital distribution system. Additionally, the model combines a relatively detailed modelling of the dynamics of energy consumption in the data centre together with a relatively abstract model of the broader systemic dynamics of energy consumption and its effect on the emission of greenhouse gases. We will explain the choice of these abstractions in a bottom up fashion starting with the creation of revenue and following the chain of interactions up to the <Data Centre Energy>.



Model 2. Total energy consumption.

4.2 Finances

The main drivers of revenue in the digital media business are advertisement sales, paywalls and micropayments that depend on an audience. We have excluded the interactions between the digital and print side of the business and the economics of subscriptions from the model. Through advertisement sales <Revenue from Services> then depends on some abstract measurement of service use such as impressions or clicks. Part of this revenue is then reinvested into the service leading to greater service use and higher revenue forming a reinforcing feedback loop. The balancing effect by competitors on service uptake is not part of the model. Given that revenue is a monetary value the <Service Value> then is a measure of the user value associated to the content consumed and the <Service Sophistication> is a representation of the change of this stock in time.

4.3 Synergy

The dynamics of content creation form a second reinforcing feedback loop that drives the amount of data comprising the articles, features, breaking news etc offered by the media service. The various media types have individual bit rates that require the transmission of different amounts of data for the consumption of content. When watching videos online, for example, typically 30 to 60 times as much data needs to be transferred when compared to browsing the Internet whilst mainly text and graphics are being transferred (Preist and Shabajee, 2010).

In order to work at a level of abstraction that allows scenarios to be explored without extremely detailed modelling we have introduced a variable to represent the idea of content synergy. Synergy results from the amalgamation and cross-linking of media forms as text is increasingly merged with video, audio and images. This mechanism can significantly increase the amount of data transferred to users when consuming published content. By making choices over published

content an online media services provider has some, but not complete as we discuss later, control over the amount of data sent to the user. The variable <Richness> is an abstract representation of this idea and represents balance between simple text and multimedia rich content. Although not fully defined in this paper its dimensions are known, $\text{MB s}^{-1} \text{ \$}^{-1}$, and it could be measured as an index. We can speculate that is some measure of the *rate of added value* to the user.

The value of the service to the end user is a stock <Service Value> that accumulates the product of content <Content Synergy> and capital investment in services that we have termed <Service Sophistication>. Capital investment can be understood as the amount of revenue re-invested into the creation of the raw journalistic material that makes up content.

Forces outside of the control of a media service provider also drive synergy. Social media technologies, such as twitter, result in mutualisation whereby a provider's content is linked to non-provider content and vice versa. The variable <Richness> thus also needs to capture the notion of mutualisation too. Our assumption is that mutualisation grows proportionally to the user value that can be attributed to the published content. The more original the content is, the more frequently it is likely to be linked to by non-provider sites.

However, we are only at the beginning of understanding the dynamics of mutualisation. Moreover, from a life cycle assessment perspective the allocation of data volume as a proxy for carbon emission is unclear with regard of content generated through mutualisation. Who should be held accountable for data consumed by users, the creator of the original content or the syndicator? For these reasons we have not included the effect of mutualisation in the model, although it is amalgamated into the variable <Richness>, and is an active area of further research.

4.4 Energy

The variable <Content Synergy> captures how data volume relates to content. The total data transmitted is the product of the number of users <Users> and the time each user spends consuming digital media <Attention Time> represented by the variable <Data Volume Consumed>. We calculate the <Data Centre Energy> as the product of <Energy Consumption by Data Volume> and the total data volume served. The growth of the user base is dependent on increasing service value as well as on an increase of global access to digital media, and any service provider has the potential to achieve very wide reach outside of its national market; indeed if it even considers itself to be limited to national markets.

The total need for energy also depends on the power drawn by network infrastructure and user devices. The contribution from user devices depends on their number and their individual energy consumption. The <Data Volume Consumed> has an influence on the number of devices as increasing demand on computational power drives device sales. In a more detailed model the impact of idle time energy consumption could be included. If users turn devices off when not in use energy consumption is reduced. By raising awareness of these issues user behaviour can be modified and thus the impact on the energy consumption through end user devices can be reduced.

The variable <Affluence> represents the influence of purchasing power on the number of deployed end user devices. Also, the amount of retired devices is directly dependent on the purchase of new devices although we have yet to fully account for the second-hand device market.

4.5 Sustainability and Energy Efficiencies

The greenhouse gas emissions related to the consumption of energy are dependent on the carbon intensity of energy. We have modelled socio-political and economic pressure both as monetary values. The economic pressure is calculated from the price of energy. The socio-political pressure is calculated from the price of carbon dioxide equivalent emissions. In the wider systemic context this pressure contributes to improvements in energy efficiency of technology provided by IT vendors. These improvements act on the energy consumption of the server technology, the network infrastructure and the end user devices. However, the dynamics of these relationships involve the principles behind Moore's law, advances in utilisation of servers by techniques such as virtualisation and improved data centre cooling. Our understanding of the dynamics of these processes in a systemic context as they are driven by economic and socio-political pressure is still at the beginning and it was decided to make them exogenous to the model. They are represented as a constant improvement factor on energy consumption by the variable <Industry Normal Efficiency Gain>. The effect of the efficiency gains on end user devices are represented by the variable <Average Device Energy Consumption> that also contains a constant improvement factor in energy efficiency.

For any business seeking to establish a leadership position in sustainability the concept of socio-political pressure manifests itself in strong commitments to investing into the sustainability of its operations. Whilst such a business cannot directly influence the availability of more energy efficient servers for their data centre servers it can favour the replacement of servers for more efficient recent models on the grounds of increased sustainability, even if it was not justifiable on economic terms alone.

5 SCENARIO DEVELOPMENT

5.1 Control variables

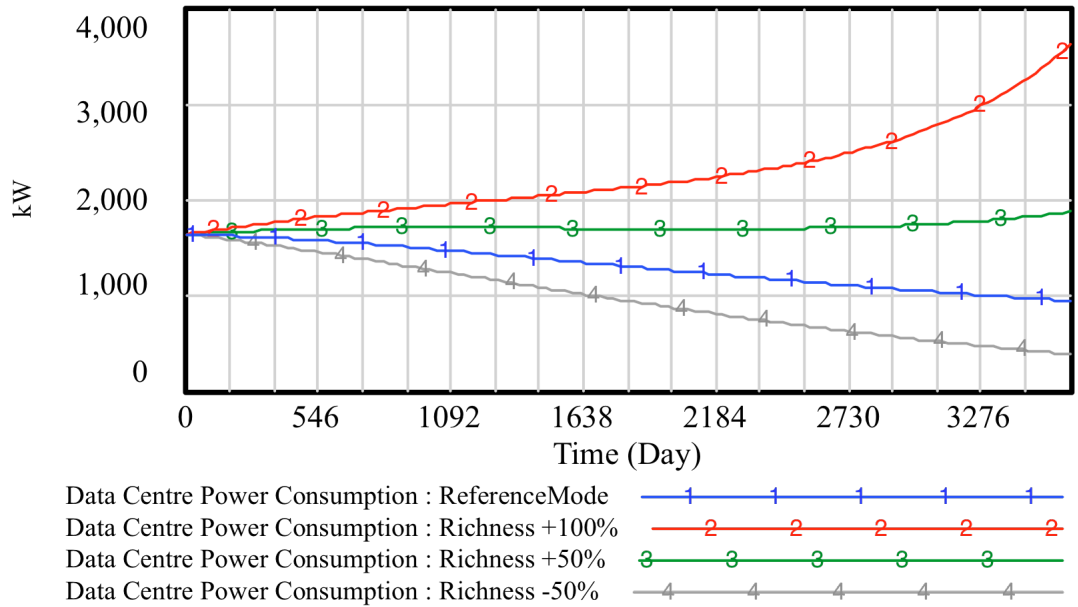
As a tool to inform sustainability strategies the model has variables that are under a varying degree of control. Firstly, the <Richness> of their content, the investment in service improvement inform <Content Synergy> and thus have a direct impact on <Data Volume Consumed>. Also informing <Data Volume Consumed> are <Attention Time> and the number of <Users>.

5.2 Calibration

We have calibrated the model to explore the dynamic behaviour through the variation of <Richness> over a ten year time period as shown in Figure 1. Our investigation as reported in this paper was not interested in the absolute prediction of energy consumption in the data centre, although the model is parameterised according to Table 1 and produces a reasonable baseline measure of 1.6MW expressed as power. We were interested in discovering the boundaries of <Richness> that would lead to substantially different future states. Given that the model has only one balancing feedback loop we can see by inspection that we would expect exponential growth, decline or some rise/fall or fall/rise depending on its relative strength. Calibration was needed to determine values for the abstract variable <Richness> which is measured in units of $\text{MB s}^{-1} \$^{-1}$. Four scenarios have been defined that all start with the same level of <Richness>. They differ in respect to the ratio of the final value of <Richness> compared to the starting value, with the change in time modelled as a simple linear ramp. In the 1st scenario, <Richness> is maintained at its initial value (Reference); in the 2nd scenario the value of <Richness> at the end of the simulation time is +100% of the initial value. In the 3rd scenario the value is +50% of the initial

value and in the 4th scenario -50%. The value to the user, as expressed in the stock <Service Value>, always increases.

Data Centre Power Consumption



Service Value

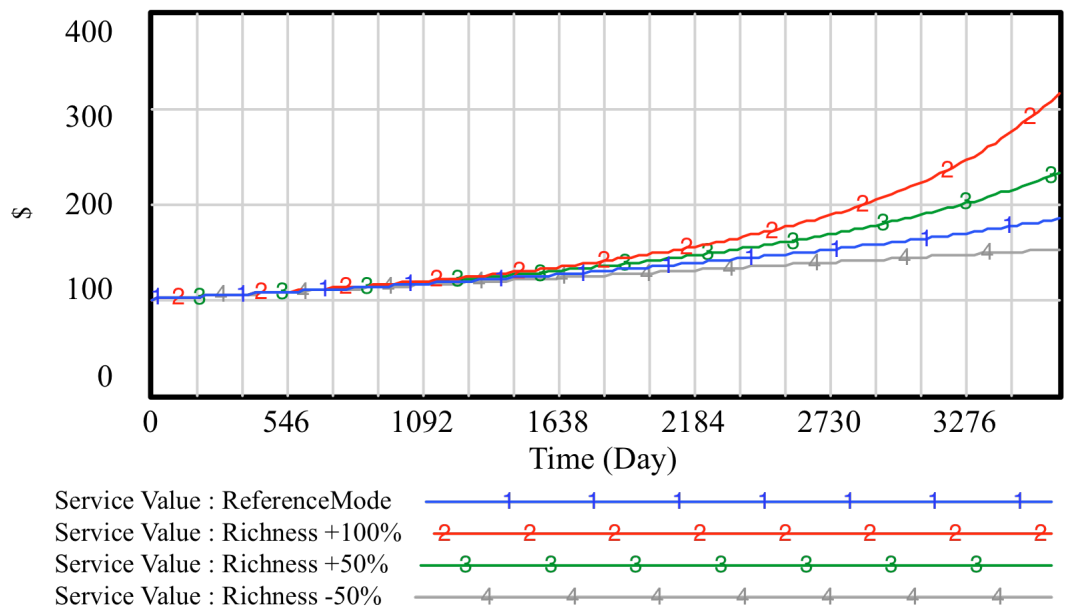


Figure 1. Data centre energy consumption boundaries for 4 scenarios ranging from an eventual 50% reduction in Richness to a 100% increase in richness. Scenario 1 represents no change in Richness as a Reference. Note that for all 4 scenarios, the Service Value, normalised to an initial value of \$100 always increases.

Variable	Value	Unit	Ref	Remarks
Initial time	0	Day		
Final time	3650	Day		The simulation time frame is ten years
Initial number of Users	2×10^6			Arbitrary number of users
Daily growth	0.05	%		
Attention Time	1/24	Day	3	Assumed to be similar to behaviour in the US
Data centre energy efficiency improvement	24/365	%/Day	4	Performance improvement is assumed to be constant.
Cost of Energy	2.86×10^{-8}	\$/Joule	5	
Cost of mitigation	0.02	\$/kgCO ₂	6	Numeric value based on current carbon prices per tonne CO ₂ eq. emission
Carbon intensity	1.39×10^{-7}	kgCO ₂ /Joule	7	
Initial energy consumption	1.688	Joule/MB	8	
Investment Rate	5×10^{-9}	1/MB	4	
Initial service value	100	\$		Abstract value. Change of value over time can be interpreted as relative increase of user value

Table 1. Model parameterisation

6 DISCUSSION

6.1 Reflection on the Modelling Process

The modelling process can expose the limits of our understanding of the system. In this instance the difficulties of linking the economic and socio-political pressure back to efficiency gains pointed to the need to understand the dynamics of this process. Additional insight was gained from understanding that the reinforcing feedback dynamics around the synergy of content could be modelled through combining abstractions of several concepts into a single concept. Essential to the success of this abstraction was the strict maintenance of dimensional consistency. The need to embed the concrete and relatively detailed system of a media service provider with the abstract global system of digital media consumption caused the partitioning of the model. The forward propagation of dynamics from the concrete system to the general was trivial while the closing of the balancing feedback loop towards efficiency improvements in energy consumption remains problematic.

³ Anon. Americans Spending More Time Following the News. Pew Research. 2010. Available at: <http://people-press.org/report/652/> [Accessed March 9, 2011]

⁴ (Preist and Shabajee, 2010)

⁵ Energy D of. Electric Power Monthly - Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State. Available at: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html [Accessed February 28, 2011]

⁶ Anon. Price of carbon certificate at BOERSE MUENCHEN EUA (WKN A1A4YF, ISIN DE000A1A4YF4) - Chart - ARIVA.DE. Available at: <http://www.ariva.de/chart/?secu=102516234> [Accessed March 9, 2011]

⁷ Anon. A Note On Variations in UK Grid Electricity CO₂ Intensity with Time - Earth Notes. Available at: <http://www.earth.org.uk/note-on-UK-grid-CO2-intensity-variations.html> [Accessed March 9, 2011]

⁸ Greening the Internet with Nano Data Centers. Available at <http://www.thlab.net/~lmassoul/conext19-valancius.pdf> [Accessed July 26, 2011]

6.2 Results

Both the structural properties as well as the dynamics of the model clearly suggest that there are few points of intervention for a media service provider to contain energy consumption of its data centre operations if user numbers as well as volume of contents keep increasing. The scenarios suggest that if the user base, as well as the data volume, grows exponentially the growth of energy consumption by servers cannot be compensated by improvements in efficiency and will grow exponentially. The efficiency gains in server technology resulting from Moore's law are outweighed if current trends are sustained. The most direct point of control is the richness in the mix of video, audio and text. If the data volume of published content can be effectively reduced a very large decrease in energy consumption in the data centre will result. The absence of discourse around the energy impact of data volume suggests that there has so far been little awareness in the digital media industry for this potential problem.

6.3 Processes to Follow

Apart from the growth of the audience and the increase in multimedia richness of content mutualisation impacts the data volume associated to published content. In our exploration we have deliberately excluded mutualisation as a driver of dynamics. More qualitative as well as quantitative research is necessary to understand its influence.

We have represented the improvements in energy efficiency of computing as a constant increase. In a systemic perspective among others the economic pressure will drive this. However, more research is needed to explore the dynamics underpinning Moore's law. Additionally, efficiency improvements in the data centre have recently been achieved through technologies such as virtualisation. Specifically relevant to the data volume of media content are the dynamics of synergy that also needs further investigation.

6.4 Model Validation

The purpose of the modelling activity reported in this paper was to explore the boundaries of energy use scenarios for the delivery of online media services. Whilst this has been achieved, the abstractions introduced in order to complete the task have raised some interesting research questions about the relationship between richness, synergy and mutualisation that requires further modelling. For the purposes of validating the existing model we propose that the variable <Richness> corresponds to an index that could be measured since we know its dimensions – $\text{MB s}^{-1} \text{\$}^{-1}$. Once defined, a suitable longitudinal study could be introduced to monitor and report on the index. It is likely that as modelling develops this will be decomposed into its contributing parts as these become better understood.

As (Coyle and Exelby, 2000) state there is no such thing as absolute validity, only a degree of confidence which comes as the model is scrutinised and found to meet its purpose. They particularly flag the significance of dimensional consistency as a “*sine qua non*” of model validation. For our work this has been invaluable as a means of introducing abstractions that are correct, dimensionally, but yet to be worked out in detail. Again following (Coyle and Exelby, 2000) we believe that the model has met its purpose and decisions about boundary selection, i.e. system from a media service provider perspective, means that we have investigated how global economic and socio-technical pressures have been brought into the model endogenously. Those variables remaining that are exogenous are out of the control a media service provider but are easily measurable. Ultimately we have been less concerned with black-box style numerical prediction of future energy use scenarios but in “*white-box*” theory-like or causally descriptive

models i.e. we are observing the “*right behaviour for the right reasons*” (Barlas, 1996).

The model is not sufficiently complex to require sophisticated techniques to understand loop dominance. It is clear that content richness and synergy drives energy use compared to energy efficiencies that can be gained in the data centre. It is unlikely that most media service providers would ever have the resources to significantly out perform what has been modelled as the <Industry Normal Efficiency Gain>. Mitigating actions around richness and synergy require far more detailed modelling that is the subject of further work. As in the case described by (Barnes, Burton, Hawker and Lyons, 1994) discussed earlier it is likely that analytical models will be required and that tools such as Eigenvalue Elasticity Analysis (EEA) as described by (Gunalp, 2006, Kampmann and Oliva, 2006, Saleh, Oliva, Kampmann and Davidsen, 2009, Schwaninger and Groesser, 2009, Taylor, Ford and Ford, 2010) will be appropriate as we delve into the problem of modelling richness, synergy and mutualisation.

7 CONCLUSIONS

According to the model we have developed the future dynamics of energy use for the delivery of media services are apparently bounded by three factors; i) the overall energy efficiencies deliverable by the ICT supply chain into the data centre, ii) the overall media “richness” of content and how that is effected by investment and mutualisation, and iii) growth in the user base.

User growth can be estimated using traditional marketing techniques and is not discussed here. For the purposes of exploring scenarios modest exponential growth was assumed.

A media service provider is unlikely to significantly outperform the energy efficiencies available to them through their IT supply chain although their policies will likely lead them to investing above industry norms in order to achieve the maximum possible. In the case of a business seeking to establish a leadership position in sustainability it is likely that it will be seen to be quite responsive to the socio-economic pressure to mitigate the impact of greenhouse gas emissions.

The questions arising from the use of the abstractions richness, synergy, and mutualisation have opened up a profitable area of further work to explore. We do know that we can define an index of richness measured in units of $\text{MB s}^{-1} \$^{-1}$ which seems to correspond to the concept of *rate of added value*, and that for data centre energy use not to exceed current levels, *ceteris paribus*, <Richness> must not grow above ~20% of its current value. What this means in practice requires further modelling effort to understand these effects and further theoretical work to understand how diffusion models can help with dealing with markets that contain non-perfect, or partial, substitutes. Since mutualisation introduced a significant unknown into managing energy costs we can postulate simple mitigating actions, such as introducing pay-walls, to control them. However, since it is data *rates* that are crucial in managing the energy budget we suggest a profitable area of future work would be in exploring the use of throttling mechanisms similar to the way in which networks can be configured to deal with outbreaks of virus infections (Williamson, 2002, Williamson, 2003).

Although the transition from print to online digital media is not modelled here as part of the overall strategy effort within SYMPACT and this needs to be integrated with the modelling presented in future work.

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