International Exergy Economics Workshop: University of Sussex, 13-15 July 2016
Parallel Session Abstracts

Day 1 – Parallel sessions 11.00-12.30

Session 1A: Human development & energy services and needs: Chair – Nina Eisenmenger

"Improving human well-being within environmental limits: the role of energy services and human needs" - Lina Brand Correa

The current context of climate change poses great challenges to modern developed societies, amongst which is to maintain current levels of well-being without having a negative impact on the Earth's ecosystems. In this context, energy can be seen as one of the links between environmental impact and human well-being: energy is the main source of greenhouse gas emissions, and the services provided by energy are vital to support human development. In order to address such a challenge we argue that two conceptual changes must be made. On the one hand there is a need to understand energy use beyond the traditional category of final consumption (and beyond even the more accurate and recent useful exergy concept) towards energy services. On the other hand, there is a need to understand human well-being beyond the traditional economic categories towards human needs. This presentation aims to, firstly, explain the advantages of making the abovementioned conceptual changes. And secondly, to discuss the methodological possibilities of relating energy services and human needs, in order to find policy relevant alternatives to improve human well-being within environmental limits.

"Useful exergy in the developing world: Case study – Ghana" - Matt Heun

Development of societal exergy and useful work time series began with industrialized countries (US, UK, Japan, and Austria) about 15 years ago. Recently, analysis has been extended to Portugal and China. Promising insights from the exergy literature include deeper understanding of how and why energy drives economic growth and societal development (Ayres and Warr), nuanced projections of future energy demand (Brockway), and cointegration of energy and economic output (Domingos and Santos). To date, the developing world (save China) has been excluded from societal exergy analysis, leaving a gap in our understanding of the role of exergy and useful work in economic development. But, interestingly, the estimation of China's societal exergy time series (Brockway et al.) showed that exergy and exergy efficiency trends of developing nations may differ significantly from those of western countries. This suggests that (a) developing nations may have different exergy and useful work consumption patterns compared to developed nations and (b) there is a need to create exergy and useful work time series for additional developing nations. This presentation will provide an update on the effort to generate exergy and useful work time series for Ghana as an African developing nation. Comparisons are made to China, the UK, and the US.

"Linking useful exergy to energy and material services" - Jonathan Cullen

Useful exergy is an important metric for understanding the efficiency of the energy system and the drivers of economic growth. Yet useful exergy by itself is useless, unless it is used to deliver the energy and material services people want. Heat delivered in an open desert, trains carrying no people, and food that is never eaten, are all examples of useless useful exergy! By understanding the links between useful exergy and the energy and material services desired by consumers, we can find ways to make useful exergy even more useful.

Session 1B: Visions and Policies for the Future: Chair – John Barrett

"Pandora and Thanatia: a thermodynamic vision of the mineral resource depletion" - Kai Whiting
Mineral resources are becoming increasing exhausted. This phenomenon is due to a combination of the pressures exercised by the mining industry and the habits of human consumption. Through the thermodynamic tools of the exergy analysis it is possible to value this exhaustion. However, the "language" of exergy and thermodynamics does not always facilitate information transfers away from engineering and into the spheres of business and public policies. This paper is a reflection of resource depletion written in a didactic way so that all individuals can understand its criticality. Borrowing from two celestial bodies: Pandora of James Cameron's Avatar and the hypothetical crepuscular planet Thanatia, the authors explain exergy, the reference environment and the tools involved in resource management. The paper also states the need for a greater level of awareness in the taking of decisions that support both sustainable development and the protection of geological heritage.

"The macroeconomic impacts of reducing energy use: Digging into the debate" - Lukas Bunse
In my PhD I am exploring how we can substantially reduce energy use in the economy in a socially sustainable manner. I am specifically interested in the potential macroeconomic impacts of energy efficiency improvements, higher energy prices or fossil fuel scarcity, and why opinions on the significance of these impacts diverge so widely in the academic community. While some heterodox economists warn that large-scale reductions in energy use are incompatible with business as usual and economic growth, most economists and policy makers consider a decoupling of economic growth from energy use a feasible way forward. I am currently reviewing the literature on the topic to try to unpack this divergence. Why do some economists think that a reduction in energy use (whether voluntarily or resulting from the depletion of fossil fuels) will have such problematic impacts on the economy? What are the mechanisms they propose through which these impacts will manifest themselves? How, if at all, are these mechanisms considered in different macroeconomic models? In my further PhD studies I am hoping to build on the findings of this review by conducting empirical research targeting some of the mechanisms identified.

"Energy demand modelling for Government" - Sarah Livermore
The Government publishes annual projections of UK primary and final energy consumption and greenhouse emissions (the EEP). These are used by Government and external bodies such as the Committee on Climate Change to monitor progress towards legally-binding UK emissions targets (carbon budgets) and identify the level of additional mitigation effort needed to meet those targets. In recent years, policy makers have become increasingly interested in the level of decoupling of energy consumption from GDP in the projections, to investigate ways of further reducing the former without adversely affecting the latter. I will describe the underlying approach that is used in the EEP to model energy consumption, together with the annual cycle of model development and collation of input data. I will also discuss the quality assurance standards that Government models must meet, when being developed both in-house and also through external collaboration.

"Energy and Economic Growth: Why we need a new pathway to prosperity" - Tim Foxon
This talk will set out the aims and structure of a new book (to be completed) which will examine the history of the role of cheap fossil fuel energy sources and technologies in past long waves of economic growth, and the implications of this for a sustainable low carbon transition.

Session 1C: Energy Efficiency and Technology - Chair: Tania Sousa

"Exploring the exergy intensity and efficiency of mineral resources" - Luis Gabriel
Exergy can be used to analyse the relationship between energy and mineral resources. It allows us to evaluate the physical value of a commodity because it takes into account its criticality based on the ore grade or rarity, rather than its mass. This is relevant for sustainability policies regarding the value given to non-renewable natural resources by governments and societies. In addition, we analyse the effect of ore grade in the exergy efficiency of mineral production. National scale examples of the relevant Colombian minerals balances and Australian gold and copper production are presented.

"How do we get exergy analysis used by process plant managers, to unlock plant-level resource efficiency opportunities?" - Ana Gonzalez Hernandez
As awareness about climate change increases and concern grows, manufacturing companies are increasingly being required to be more transparent and demonstrate environmental accountability. However, current process control of plants does not consider environmental impacts, and is instead focused on maintaining process equilibrium, product quality and safety. At the same time, resource efficiency analyses typically focus on either materials or energy, without considering the interactions between them. This makes it impossible to characterise the efficiency of material-converting processes and to compare process efficiency across different material production systems or industrial sectors. Exergy provides a solution to these issues by allowing energy and material flows to be compared using a single metric, and by characterising the efficiency of energy- and material-converting processes. Using exergy as a measure of resource flows: provides a dimensionless measure of resource efficiency that can be compared across any type of process, allowing the prioritisation of improvement measures; gives a better understanding of the interactions between resources; and reveals insight into the loss-mechanisms and performance of processes with respect to an ideal operation. Despite these benefits, the concept of exergy is rarely used in industrial practice. This research explores whether exergy could help plant managers improve resource use, and if so, how?

"Three-level energy decoupling" - Zeus Guevara
The Portuguese energy sector experienced a substantial transition into natural gas and renewables in the last two decades. During the same period, the Portuguese economy continued a transition into a service economy. The combination of these two transitions significantly influenced the trends of primary energy use and intensity. The goal of this analysis is to identify the main factors driving the changes in primary energy use (PEU) in Portugal over the period 1995-2010. The analysis was carried out with the input-output model that allows accounting for useful exergy and the final-to-useful conversion stage in the economy. Portugal experienced a relative decoupling driven by three main decoupling forces: the energy sector transition, economic structural changes and improvements of the useful work intensity. The results indicate that the primary-to-final conversion and useful-to-service transfer of energy flows significantly contributed to energy decoupling while the final-to-useful energy conversion had a counteracting effect. The latter fact suggests that policies targeted to increase technical efficiency in industries were ineffective with respect to energy decoupling. Finally, it is concluded that the analysis of energy decoupling is improved by the inclusion of three levels of energy use, i.e. primary, final and useful.

"Energy savings in European Manufacturing: an historical perspective" Sofia Henriques
The 19th and the 20th century was a period marked by industrialization and increasing energy consumption but at the same technological progress which improved the efficiency of energy use. Although energy efficiency has been considered the main offsetting factor of rising energy consumption and CO2 emissions, there are surprisingly very few studies on historical paths of energy efficiency and energy efficiency differences across countries. Although useful, these studies concentrate in explaining the differences in economic energy intensity (energy/value added) and do not therefore capture accurately the role of energy efficiency. The project I am presently conducting in my research stay in Cambridge (May-July) aims at tackle this shortcoming, by providing new estimates of long-run energy efficiency trends in the manufacturing sector for a group of European Countries (Portugal, Spain, France, Germany, Denmark, Norway, Sweden and the UK) and the United

States. The results of this study will allow firstly the historical quantification of the energy savings of the industrial sector by subsector and by country over a very long-run period of time (1870-2013). Secondly, by providing energy efficiency estimates which are country-specific, this work will be able to quantify the technological disparity across countries and the periods of convergence and divergence in energy efficiency. Of particular importance will be to investigate the role of globalization in spurring technological convergence or specialization across sectors. Thirdly, this project will construct a long-run index proposed by the literature as a good measure to capture developments in energy efficiency as an alternative to the most commonly used energy intensity (energy/Value added): the ODEX (proposed by the European Union, based in an energy/ton metric for the most energy intensive sectors: pulp, paper, cement and iron & steel with an energy/production values (in constant prices) for the non-energy intensive sectors. This workshop will provide an opportunity to present preliminary results for some of these countries and discuss some possibilities of comparing this index with more data intensive exergy indexes.

Day 2 – Parallel sessions 11.00-12.30

Session 2A: Probability, Uncertainty and Estimation in Modelling Energy and Economics – Chair: Matt Heun

"Energy Technology Investment Decision-Making under Multi-Dimensional Price Risk" - Reinhard Madlener
Decision-making with respect to long-lived irreversible energy investments under uncertainty calls for multi-dimensional models that are able to account for the unknown price trajectories of all the different prices of the underlying commodities (fuel input, CO2 permits, and electricity output). For such scenario-based analysis, deterministic approaches are commonly used that assume a constant rate of change for each price; these price trends are then varied within a realistic range to check for the robustness of the model outcomes. More sophisticated approaches for dealing with price uncertainty make use of stochastic models, which can be classified into those that (1) use stochastic processes for electricity prices, commodity prices, and other uncertain parameters (such as hydro inflows, solar irradiation, or wind distributions); (2) enable scenario generation and reduction; (3) allow the stochastic optimization of investment decisions, including short- and mid-term electricity generation planning and long-term system optimization. In recent years, the application of real options (RO) models to decision-making processes in the energy sector, especially for investments in new power generation infrastructures, has increased considerably. A generalized RO model is presented that, in contrast to more conventional RO models used, accounts for multiple commodities by correlated stochastic price paths with a combined evaluation of an arbitrary number of available technologies.

"From theory to econometrics to policy: Insights and cautionary tales from macroeconomic growth modeling with the CES production function under an ecological economics framework" - Joao Santos
Development of macroeconomic models that inform government policies is always pursued within a theoretical framework under which relevant modeling choices are evaluated, appropriate econometric techniques for parameter estimation are implemented, and criteria to select which among many models best represents the economy are applied. Aggregate production functions, such as the increasingly popular Constant Elasticity of Substitution (CES), lie at the heart of this process. In our work we adopt a systematic approach to investigate the impact of several modelling choices – framed by ecological economics – on CES models, and formulate specific policy measures. Namely, we tackle the following issues in a systematic manner, as no study has before: (a) removing the neoclassical assumption that equates historical cost shares for factors of production with their respective marginal productivity; (b) including energy as a factor of production; (c) quality-adjusting factors of production; and (d) comparing between possible nesting structures for three-factor CES models. Using empirical data for the UK and Portugal for the time-period 1960-2009, we test separately and in combination the effects and policy implications of these four design choices, while also calling attention to the pitfalls inherent to each step in the theory-to-econometrics-to-policy approach to macroeconomic growth modelling.

"Estimation of substitution elasticities in three-factor production functions: Identifying the role of energy" - Julius Frieling
Energy demand and its consequences for the environment are global problems, but the possibilities of empirically analyzing multi-factor production models to understand aggregate demand remain limited. This paper demonstrates how the parameters of a nested CES production function with non-neutral technical change can be identified using a system of equations approach. With this method, we examine the role of energy inputs in an aggregate CES production function and identify its elasticity of substitution using data for Germany. Holding the intraprocess elasticity in the nested process fixed allows a realistic model of the role of capital/labor substitution for energy demand. Our findings show that the elasticity of substitution between energy and the capital-labor composite is very low, only around 0.3. This means that energy availability could be a severely limiting factor for growth. Another implication is that productivity gains for capital and labor are energy using, owing to the near-Leontieff nature of energy inputs.

"Beyond mean models of energy/energy and economic growth"- Vlasios Voudouris

I am to bring into focus the idea of econometric analysis where the whole shape of the distribution of economic growth is allowed to vary according to three factors of production, namely energy/exergy, labour and capital. The aim is to argue that future research directions of energy/exergy-economics needs starting to think about models beyond the mean or expected growth. While a focus on expected growth may entail easy interpretation of the estimated effects (particularly when linear models are used), it often lead to incomplete analyses when more complex relationships are indeed present (such as non-parametric smooth functions) and also bears the risk of false conclusions about the significance/importance of the factors of production for higher order characteristics (e.g., variance, skewness and kurtosis) of economic growth. I will therefore give an overview of an extended type of econometric models that allows us to go beyond mean models. More specifically, I will consider a class of generalized additive models for location, scale and shape to better explore the interaction effects of economic growth with three key factors of production.

Session 2B: National Accounting and Modelling for Energy, Materials and Economics - Chair – Peter Taylor

"National exergy accounting: A quantitative comparison of methods and implications for energy-economy interaction analysis" - Jack Miller

Assessments of the feasibility of decoupling energy consumption from economic growth could benefit from an improved understanding of the size, nature and value of different energy flows. This understanding may be enhanced by focusing upon useful exergy. Useful exergy flows within national economies are increasingly being quantified and their role in economic activity explored – however, exergy economics currently lacks a consistent methodology. This analysis contributes to the development of a more consistent approach; by constructing a 'useful exergy account' for the United Kingdom covering the period 1960-2012, we explore how different methodological choices influence estimates of useful exergy for particular categories of end-use together with total national useful exergy consumption. Specifically, we evaluate the effect of different choices for the number of categories of useful exergy, the boundaries between those categories, the method of estimating exergy efficiency of the heat and mechanical drive categories, and the method of estimating the primary exergy associated with nuclear and renewable electricity. This leads to suggestions for best practice when constructing such accounts, and the identification of areas where further methodological development is required. We conclude by highlighting some valuable future applications of this more consistent methodology.

"Insights from the application of the Cambridge Econometric model (E3ME)" – Sophie Billington

E3ME is a simulation model of the worlds' economy, energy balances and air-borne emissions, disaggregated by 59 countries or world regions. The model provides policy relevant insight by coupling the consumption and production of energy to a structural model of the economy. The model is used by policy-makers across the world to determine the impact of changes in the economy on the energy system and GHG emissions and, perhaps more importantly, the impact that changes to the energy system have on the economy and society. Recent examples include:

1) a socioeconomic assessment of the impact of global renewable energy deployment for the International Renewable Energy Agency (IRENA)
2) a socioeconomic assessment of the 2050 Energy Roadmap for the European Commission
3) a socioeconomic assessment of the take-up of increasingly efficient and electrified passenger cars in Europe for the European Climate Foundation, entitled "Fuelling Europe's Future"

As a simulation model, E3ME does not assume the theoretical underpinnings of a standard Computable General Equilibrium (CGE) model, instead attempting to simulate behaviour based on observations of the past, leading to starkly different conclusions for policy makers than the standard approach.

"Hybrid energy system models: assessing technological mitigation pathways from INDCS towards 1.5'C with TIAM and IMACLIM-KLEM" - James Glynn

Bottom Up (BU) techno-economic models often times give insights into the technical possibilities to Climate Change mitigation without representing the macroeconomic transition pathways with sufficient realism and feedback. Top down (TD) macroeconomic models give greater macroeconomic realism of the long term dynamics that drive the global energy system, but suffer from a lack of technical realism. What are the financial mechanisms required invest in radical infrastructure role out? What are the requirements upon the labour force for training and employment to implement the transition? What are the achievable rates of decarbonisation without driving the global economy into recession? This presentation summarises collaboration between CIRED and University College Cork which hybridises ETSAP-TIAM - a technology rich BU global energy systems model - with a reduced form 2 sector multi region macroeconomic (IMACLIM KLEM) TD model. We explore the feedbacks to energy service demand and economic growth in a decarbonising energy system under the perspective of new global macroeconomic reality of slower than expected growth, while aiming to move from INDC pledges towards 1.5C mitigation pathways.

"How exergy-cost analysis can improve on some macroeconomic aspects of the UN's System of Environmental-Economic Accounts (SEEA) - Antonio Valero

All economic activities entail, somehow, degradations of natural resources. In microeconomics, depreciation is considered a monetary asset compensating for the physical degradation of machinery etc., produced ultimately from raw materials that gradually become dispersed. This is supported by the accountants' principle of 'keeping capital intact'. In fact, such money allows for buying new machinery; and there is thus an implicit assumption of equivalence/reversibility between money and material goods. From a macro-economic point of view, however, the Earth's natural capital of economically useful minerals is irreversibly depleted since the energy radiated here from the Sun cannot restore those minerals. (Economically useful minerals can yield money but money cannot create economically useful minerals.) Replacement exergy-cost analysis can quantify, across the board using a single kind of unit of measure (such as kilowatt hours), all the depletions of mineral natural capital. These exergy costs are measured by reference to the 'economically dead' baseline of 'thanatia', a theoretical condition of the Earth crust whereby there would be no ores at all. The U.N.'s System of Environmental-Economic Accounts (SEEA) could improve its minerals-depletion analysis by means of such an approach.

Session 2C: Provocations - Value in Thermodynamics and Economics - Chair – Tania Sousa

"'More Heat Than Light': The Use and Abuse of Thermodynamic Ideas" - Geoffrey P. Hammond

The 'Laws of Thermodynamics' were postulated after the practical development of early heat engines. James Watt's double-acting rotative steam engine (1788), for example, predated the Sadi Carnot's theoretical engine cycle (1824). In the modern era, the requirements of engineering thermodynamics, heat transfer and work constrain energy systems. But the implications of these phenomenon are often not well understood by those engaged in energy systems analysis. There is some confusion, for example, between the concept of 'heat' and 'useful work done'. The former occurs over a temperature gradient and consequent range of van Gool's thermodynamic quality (= exergy/enthalpy), whereas the latter reflects services provided by electricity (such as lights and appliances) or by mechanical drives. So they are physically quite different phenomena and should be treated as such. The thermodynamic property nowadays commonly known as exergy is derived from the First and Second Laws of Thermodynamics, although exergy analysis is often (mistakenly) termed a Second Law analysis. Power generation, together with final energy demand in the domestic sector and in transport, account for nearly eighty percent of exergetic improvement potential in the UK economy (Hammond & Stapleton, 2001). Poor thermodynamic performance across the energy sector is principally due to exergy losses in combustion and heat transfer processes associated with electricity generation, space heating, and the main transport modes. This presentation will therefore address these and other misuses of the thermodynamic ideas; principally outside the initial realm of engineering thermodynamics. They have been utilised by practitioners in a variety of disciplines, including ecology, economics and environmental

sustainability. Thus, exergy has been viewed as providing the basis for a tool of resource and/or emissions accounting, although the behaviour of energy and matter are actually not equally mirrored by thermodynamic laws. Indeed Söllner (1997), Hammond (2004) and Hammond & Winnett (2009) argued that thermodynamic insights are typically employed beyond engineering thermodynamics simply as analogues or metaphors of reality. They should therefore be empirically tested against the real world.

The Useful Concept of "Thermodynamic Rarity" - Mark Lindley

Antonio and Alicia Valero (at the University of Zaragoza) make quantitative assessments of each kind of mineral commodity in terms of its "thermodynamic rarity", defined as the amount of exergy that would have to be spent in order to get from ordinary rock (i.e. not from ore) a desired amount of it, purified to the desired extent, using the best prevailing techniques. With this concept one can take into account, at once, both (a) the expenditures of consumable energy in the mining, beneficiation and purification processes and (b) the natural bonus of having access to concentrated mineral deposits (ores) in the first place. (Mining causes the remaining amount of the bonus to decline; this jacks up the cost of subsequent mining; and so the Valeros' method of assessment can help harmonize the thinking of exergy economists with that of mainstream energy economists). While thus defining a "thermodynamically rare" chemical element as one that is scarce and/or costly energy-wise to process, the Valeros assess, in collaboration with Nadja von Gries, the "composed thermodynamic rarities" of the sets of materials used in this and that kind of electric and electronic appliance sold to consumers – an assessment useful for setting priorities in recycling.

"What do we mean when we speak of economic growth? The significance of value theory for the exergy research programme" - Gregor Semieniuk

The exergy research programme claims that a more accurate measure of useful energy inputs into production of output will reveal a tighter empirical relationship of energy with economic growth. But is the measurement of economic growth 'accurate'? GDP is redefined time and again, leading to substantial changes in its size and composition. And countries that outsource energy intensive production appear to continue to grow while net-importing embodied useful exergy. Different economic value theories give different explanations for this phenomenon by locating the creation of value at different stages of economic activity. In this brief intervention, an attempt is made to argue that the exergy research programme will benefit from thinking conceptually not only about the proper measure of energy, but also the proper measure of output, the production of which useful exergy is enabling.

"Why exergy economics is right and the neoclassical duality of quantities and prices is wrong" - Reiner Kümmel

Econometric analyzes of economic growth in industrial countries reveal that energy conversion contributes much more to wealth creation by work performance and information processing than the small cost share of (primary) energy seems to indicate, and that for labor just the opposite is true. All primary energy carriers are in principle 100% exergy. In general, time dependencies of the technology parameters of twice differentiable production functions in capital, labor, and energy take care of variations of energy conversion efficiencies and structural changes. If time series of exergy data are available that already include changes of conversion efficiencies, the technology parameters may be constants. Despite being at variance with mainstream economics, the findings that the output elasticities of energy are much larger and those of labor are much smaller than the cost shares of these factors are consistent with profit and welfare optimization. But doing such optimization in search for economic equilibrium neoclassical economists forgot to take into account the technological constraints on factor combinations. These are given by the facts that the degrees of capacity utilization and automation cannot exceed 1. Therefore, in the real world, the neoclassical equilibrium, where output elasticities equal factor cost shares and where the duality of factor quantities and prices results from a Legendre transformation, cannot be reached. For an understanding of modern economies prices are not enough. Since energy conversion matters so much for industrial production and growth, and since it is inevitably coupled to entropy production and the corresponding emissions of particles and heat via the Second Law of Thermodynamics, environmental problems will grow.