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Perspectives

What does energy mean? An interdisciplinary conversation

Janet Stephenson

Centre for Sustainability, University of Otago, New Zealand

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ABSTRACT

Single-discipline research may have limited effectiveness if it fails to take into account cogent knowledge from other fields, and especially if fails to communicate using terms that are meaningful to other disciplines and to policy makers. In the energy field, interdisciplinary research is needed to address the many complex and urgent socio-technical issues involved in achieving a more sustainable future. However, the terminology and specialised concepts that are integral to disciplines can create barriers to a comprehensive understanding of a shared field of inquiry. In energy sciences the common language of mathematics is used to help in understanding of the quantitative concepts of energy and its transformations, while the social sciences use both qualitative and quantitative means to describe society and social relationships, using the subtly different languages that are associated with different social theories. If these barriers to communication can be bridged, the benefits can be immense. I illustrate some of the misunderstandings that can occur in conversations between social and physical scientists with an imaginary dialogue. I conclude that, to work effectively across disciplines, social scientists will need to learn something of what *energy* means, and physical scientists will need to learn something of what energy *means*.

1. Introduction

The age of the polymath – where individuals could have a broad understanding of many fields of knowledge, and seamlessly create linkages between them – is over. The explosion of knowledge, the ongoing specialisation of inquiry, and the concomitant emergence of new disciplines and disciplinary journals, means that researchers frequently operate with a relatively narrow perspective on a given problem [1]. Academic disciplines have become 'like nation states of the intellectual world, with their own territories, languages, cultures and governance arrangements' [2,p. 272]. There are good reasons for the development of these nation states because they reflect the specific intellectual challenges of the different areas of interest. In energy science the common language of mathematics is used to help in understanding of the quantitative concepts of energy and its transformations, while the social sciences use both qualitative and quantitative means to describe society and social relationships, using the subtly different languages that are associated with different social theories. These languages and specialised concepts have developed from the needs of the questions under inquiry, but have the side-effect, if care is not taken, of creating barriers to a comprehensive understanding of a shared field of inquiry.

In the field of energy research this has come at a cost, as Adam Cooper points out [3]. Single-discipline research may have limited effectiveness if it fails to take into account cogent knowledge from other fields, and especially if it fails to communicate using terms that are meaningful to other disciplines and to policy makers. In particular, Adam's paper challenges the low level of use of the physical units of energy in energy-related social science literature. I would go further to suggest that the concept of energy in the social science literature is not as crisply articulated as it is in the physical sciences (although even there, as my physical science colleagues point out, energy has a number of interpretations depending on the context). Social scientists are naturally more interested in what energy means in the social world, but if some of its basic physical qualities are not appreciated then findings have the potential to be flawed, or at least less useful in an applied context.

While I agree with Adam's conclusion that, to be effective in policy, studies should take into account the physical units of energy [3], I want to extend the argument. As a social scientist, I can use terms such as kilowatt-hours or joules in an academic paper with only a sketchy knowledge of what they mean. Does this matter? Probably not, as long as I use the terms accurately. The greater problem arises if I design, implement and analyse energy-related research while failing to appreciate of some of the fundamental physical concepts

E-mail address: janet.stephenson@otago.ac.nz

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relating to energy. I contend that a failure to use energy units in a social science paper is a problem of much less magnitude than having an erroneous understanding of the basics of energy physics.

As a social scientist involved in energy-related research, much of my time is spent in interdisciplinary teams of physical and social scientists, which somewhat compensates for the absence of polymaths by creating opportunities for ongoing pan-disciplinary conversations [2,4]. I quickly found myself having to adjust my energy language to become far more precise in order to avoid misunderstandings with my physics and engineering colleagues. Over the years, I have not only noticed my own understanding of physical science concepts expand, but have also observed my physical science colleagues develop an appreciation of social science concepts and perspectives, creating a space in which we can comfortably exchange ideas and undertake research together.

But this process has the potential to be fraught. Individual team members not only bring different realms of knowledge, but also "different perspectives on the nature of the world, and different practices – such as methods of inquiry, different terminologies, and tests of believability" [2,p. 273]). If these barriers can be bridged, the benefits can be immense. To illustrate, I have written an imaginary interchange between an eager social scientist and a seasoned physical scientist as they grapple with communicating across their bodies of knowledge to design a research project. This dialogue draws from numerous conversations I have held with the physicists and engineers with whom I have been lucky to work over the past decade.

2. Conversation

Social scientist (bursts in the room excitedly): Hey, there's a new research grant available to study what happens when people start making their own energy. We should put in a proposal.

Physical scientist: Whoa there. You're talking nonsense. People don't make energy. This may seem to be nit-picking but you have to get this right. One of the fundamental physical laws is that energy is neither created nor destroyed – it can only be transformed from one form of energy to another.[1] You could use the word 'generate', but not 'make'.

Social scientist: OK, I'll try again. The research call is about people generating energy from solar.

Physical scientist: What kind of transformation are you talking about? A photovoltaic (PV) panel captures light energy from the sun and transforms it into electrical energy. A solar water heater captures heat energy from the sun and transfers this heat into the water. Which one did you mean?

Social scientist: Oh, I meant PV, people generating energy with PV.

Physical scientist: To be really accurate, it is generating *electricity* using PV. This is another bugbear of mine. People often say energy when they mean electricity, but you can get yourself into trouble that way. I've heard lay people saying that New Zealand is doing pretty well because 80% of its energy is renewable . . . but that's wrong. Around 80% of the *electricity* is generated from renewable sources, but if you look at our primary energy supply it is more like 40% renewable [5].

Social scientist: When you say primary energy, what do you mean?

Physical scientist: Well, there are different ways you can put figures on energy, and some are more useful in some circumstances, and some in others. If you're interested in how much energy is used by the people and businesses in your country, then primary energy is a useful concept. It refers to the raw energy that goes into the system before it has been transformed by human-derived processes into other forms of energy. Primary energy includes coal, gas, geothermal heat, hydro, wind and sunlight. Some of this will be used directly, such as burning coal for industrial heating, and some will be transformed into other forms of energy that will subsequently be used to do work, such as burning coal to generate electricity. Primary energy is usually measured in units of joules, with a metric prefix (a kilojoule is a thousand joules, a megajoule is a million joules, and so on). To measure large quantities of energy the International Energy Agency and countries that use imperial units typically use Tons of Oil Equivalent (TOE) as the unit. This is the energy released as heat by burning a tonne of crude oil, which is approximately 41.9 thousand-million joules (gigajoules).

Social scientist: Why is primary energy measured in joules and my power bill in kilowatt-hours?

Physical scientist: It's another convention. Household electricity use is normally measured in kilowatt-hours, where 1 kilowatt-hour is 3.6 kilojoules.

Social scientist: I've never really understood the difference between kilowatts and kilowatt-hours.

Physical scientist: It's the difference between power and energy. Physicists and engineers grit their teeth when people use 'power' and 'energy' as if they mean the same thing. Power is how much energy your appliance or your house draws each second. If you are using 9000 Joules per second, the power is 9 kilowatts. Energy is how much has been used to accomplish something over a period of time, like boil the kettle, and for electricity that's measured in kilowatt-hours. Think about it like a hose with running water. Power is akin to how much water comes from the hose each second and energy is akin to the total amount of water that has come from the hose to do some task, like filling a tub.

Social scientist: OK, got that. But let's get back to this research proposal. Are you keen? I think it's a really great topic, and PV has amazing potential to replace all of that non-renewable energy we use.

Physical scientist: I'm keen, but I don't agree with you about PV-generated electricity being able to simply replace other forms of energy. There are a few physical problems. One of them is that the sun isn't in the sky all the time, so you're only generating for part of each day, and that varies with latitude and weather patterns and time of year. Another problem is that the times when people use most power is in the morning and evening, while the maximum irradiation is in the middle of the day. Storing surplus electricity in batteries isn't yet cost-effective in most places, so most grid-connected households end up feeding power back into the grid at the same time. This can lead to issues for network companies in managing the impacts of the power surges on the system. And the energy sector still has to be able to generate and supply as much electricity to the households as if they didn't have PV, to account for times that PV isn't generating, so it's not necessarily any cheaper to run the system.

Social scientist: But can't we use the electricity from PV to replace fossil fuels?

Physical scientist: In some situations this makes a whole lot of sense, such as using it for electric vehicles, which can be plugged in at home and are really efficient. But for other uses such industrial heating, it might be much less cost-effective and efficient than using fossil fuels, at least at this point of technological progress.

Social scientist: What do you mean by efficient?

[1] However as pointed out by one of my physicist colleagues, this "law" doesn't apply in all situations. It works in everyday contexts, but in nuclear reactions mass is transformed into some form of energy, as explained by Einstein's equation $E = mc^2$. In this context there is an over-riding law, called the Law of Conservation of Mass-Energy. The sun's energy, for example, is generated in nuclear reactions in the sun's core. As a result about 4.3 million tonnes of the sun's mass gets converted into solar radiation each second.