PAUL MOBBS

A practical guide to sustainable IT

Unit 11

APC

This unit is one of 12 sections to a "A practical guide to sustainable IT", a hands-on guide to working with everyday technology in an environmentally conscious way. The guide has been written by environmental activist and ICT expert Paul Mobbs, and was commissioned by the Association for Progressive Comunications (APC) with the support of the International Development Research Centre (IDRC). To download the full text of the guide, or any of the other units, please visit: greeningit.apc.org

A practical guide to sustainable IT

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RENEWABLE POWER

When you have taken all practical measures to adapt your equipment and procedures to more efficient computing, there remains one external factor which can be improved: the power supply. Around two-fifths of the carbon emissions produced each year are the result of electricity generation.[1] By comparison, transportation produces just over a fifth, and industrial emissions are another fifth. Of the emissions from power generation the majority are the result of coal burning – and coal burning also creates problems due to the emission of acid gases, which damage wildlife and crops, and polluting heavy metals. Two-thirds of the world's power is generated from fossil fuels,[2] and although de-carbonising power production will not, on its own, solve the problem of climate change, it is an essential step in tackling the problem.

For most ICT users their source of power is most likely to be the electricity grid. Just as recent operating systems have become inextricably linked to the use of broadband data connections, much of our modern electronics is tied to the 24-hour-a-day availability of a mains power supply – and in many states there are few other options. In that respect, the modern electricity grid mirrors the global economic process generally; it is built upon an underlying assumption that there will be a never-ending supply of energy and resources in order to make society function. In contrast, users of off-grid power systems know that there are finite limits to their power supply; and the scale and seasonal variation of off-grid power systems requires that electricity use must be monitored and adapted if they are to have power available when they need it.

How we use electrical power is influenced by the equipment we use, but the source of power production has a significant effect on our ecological footprint. How you go about addressing this issue is dependent

1. International Energy Agency (2011). CO2 Emissions from Fuel Combustion. www.iea.org/co2highlights/co2highlights.pdf

2. International Energy Agency (2011). Key World Energy Statistics. www.iea.org/publications/freepublications/publication/key_world_energy_stats-1.pdf

upon the budget you have available to purchase alternatives to fossil-fuelled grid power, and your technical capabilities to purchase and operate these alternatives.

In this section we'll look at three potential options for improving the ecological impact of your power supply:

- Changing the contract or tariff paid to your electricity supplier in order to support lower carbon or renewable energy technologies – this is the simplest option as it requires little change on the part of the consumer;
- Installing a grid-connected renewable power generation system – this is a more complex and expensive option than simply changing electricity supplier; and
- Developing an off-grid power supply system – this a more technically challenging option, although in some parts of the world off-grid power supplies are the only option to run ICT equipment.

11.1. IMPROVING THE SOURCE OF YOUR ELECTRICITY SUPPLY

The ability to vary the source of your electricity supply is dependent upon the level of liberalisation of the power grid in your area. In more developed states the supply of electricity is carried out by private companies, either partly or wholly regulated by government. As part of this process consumers may have a choice of different power suppliers, and each supplier will have a range of electricity tariffs for different types of electricity generating technologies. In less developed states power generation comes in a variety of forms, from wholly state controlled to wholly privatised. The general problem here is that there is often a restricted choice of power sources available to purchase through the grid.

Different power generation technologies can be grouped according to how "green" they are (see Box 11.1). While some forms of power are obviously renewable other power sources are less beneficial for the environment. For example, municipal waste incineration can create electrical power, and it is often promoted as an environmentally advantageous technology, although research suggests that waste incineration produces less power than the energy which could be saved if that waste had been recycled,[3] especially paper[4] and plastics. In the same way, the burning of biomass (wood and plant matter) can be less damaging to the environment, but if the land the fuel was grown upon had previously been forest, or agricultural land producing food crops, the impacts are not much better than using fossil fuels. For this reason it is essential to consider what power sources are used to create the electricity that support our ICT needs. Rather than considering just the direct carbon emissions, it's important to use life-cycle analysis studies of power production which take land use change and other indirect effects into account[5].

In states with a liberalised energy supply many different producers supply the grid with power. The power produced from these sources is then balanced by the amount of power individual users buy from the grid. Therefore with a "green" energy tariff, while you may not be physically using renewable-generated electricity, the amount you consume will be balanced by the amount of renewable power entering the grid. By contracting with a provider of renewable electricity you can purchase some or all of your electricity needs from renewable sources. While the cost of a renewable supply tariff is usually higher than the average grid price, how "green" the sources are is often reflected in that price. Large-scale hydro and waste incineration are often priced around the same rate as fossil-fuelled electricity. The most sustainable sources, such a geothermal, wind and solar power are usually more expensive.

While not a solution for all the ills of the modern world, buying renewable electricity is an important step in moving society towards more sustainable operation. Unless people are willing to invest in non-fossil fuel electricity the alternatives required to address climate change will not be created. If it is affordable, buying renewable electricity is a means to encourage investment in those alternative sources of energy.

3. GAIA (2007). Incinerators vs Zero Waste: Energy and the Climate. www.no-burn.org/downloads/GAIA_Incinerators_vs_ZeroWaste.pdf

4. European Environment Agency (2006). Paper and cardboard - recovery or disposal?, EEA Technical report No 5/2006. www.eea.europa.eu/publications/technical_report_2006_5/at_download/file

5. Benjamin Sovacool (2008). Valuing the greenhouse gas emissions from nuclear power: A critical survey, Energy Policy, Vol.36 pp.2940-2953. www.nirs.org/climate/background/sovacool_nuclear_ghg.pdf The figures from this paper are quoted for each energy source listed in Box 11.1.

Box 11.1.

Impacts of electrical power generation technologies

The impacts of our electricity supply depend upon the sources used to generate it. At present the global power system is dominated by the use of fossil fuels renewable power sources make-up less than a fifth of supply. The list below outlines the impact of different energy sources, ordered from the highest to the lowest level of carbon emissions. The figures are the life-cycle emission of carbon dioxide (in grams of carbon dioxide per kilowatt-hour, $gCO_2/kW\text{-}h_e$) for a unit of electricity produced from each source:

- **Coal** ($960gCO_2/kW\text{-}h_e$) Coal is primarily used for power generation around the world. There are different grades of coal, and while high quality bituminous coal produces less carbon emissions, the use of lower quality brown coal and lignite, or even peat, will produce more.
- **Heavy oil** ($778gCO_2/kW\text{-}h_e$) Heavy oil is a low quality, sticky, tarry form of oil and for that reason it is cheaper than the price of oil quoted in the media. While its low price makes it an alternative to coal for power production, it tends to produce more soot, acid gases and heavy metal emissions than higher quality diesel fuel.
- **Diesel** ($778gCO_2/kW\text{-}h_e$) Diesel is often used for power generation as a back-up for the large power plants which supply the grid. In states with a poor quality power supply, diesel generators are often used as an alternative during blackouts.
- **Natural gas** ($443gCO_2/kW\text{-}h_e$) Natural gas is used primarily in more developed nations. As it is a higher quality fuel it produces less emissions than other fossil fuels.
- **Nuclear** ($66gCO_2/kW\text{-}h_e$) While there is much controversy over the use of nuclear power, it only makes up 13% of global power generation less than is produced from large hydroelectric dams.
- **Geothermal** ($38gCO_2/kW\text{-}h_e$) Geothermal power is produced in volcanically active areas, such as Iceland, the US or Kenya. It uses hot rocks to create steam to generate power.
- **Solar photovoltaic** ($32gCO_2/kW\text{-}h_e$) Photovoltaic (PV) cells turn sunlight into electrical power. While the greatest solar resource is in the tropics, even at higher latitudes photovoltaic cells can still produce a viable amount of power. Some manufacturers now produce solar PV kits to power laptops and mobile phones.
- **Biomass** ($14\text{-}35gCO_2/kW\text{-}h_e$) Biomass is plant matter. It can be burnt in power stations in the place of coal, or turned into liquid fuels such as biodiesel for use in generating equipment.
- **Solar thermal** ($13gCO_2/kW\text{-}h_e$) Solar thermal generation is used in desert regions, using mirrors to focus solar heat and create high-pressure gas to turn power-generating turbines.
- **Small-scale hydroelectric** ($13gCO_2/kW\text{-}h_e$) Small-scale hydro uses small flows of water in streams, sometimes without the use of a dam to trap water. As water is relatively heavy, micro-hydro is a good source of power for off-grid electrical systems.
- **Biogas/anaerobic digestion** ($11gCO_2/kW\text{-}h_e$) Biogas is created by the digestion of animal manure and plant matter by bacteria. It produces methane which can be burnt in modified generators or gas engines to produce electricity.
- **Onshore wind** ($10gCO_2/kW\text{-}h_e$) Onshore wind is one of the fastest growing sources of renewable electricity. While the largest turbines now produce up to five-million watts of power, small-scale turbines producing 75 to 150 watts can be used to power a laptop computer.
- **Large-scale hydroelectric dams** ($10gCO_2/kW\text{-}h_e$) Large hydroelectric dams which tap the power of the world's largest river basins produce 16% of the worlds power. While they produce low-carbon electricity, they are highly damaging to build and often flood valuable agricultural land and wildlife habitats.
- **Offshore wind** ($9gCO_2/kW\text{-}h_e$) Offshore wind is slightly more efficient than onshore wind because of the higher and more consistent wind resource available out at sea. Even so, it is more expensive because of the problems of building and developing turbines at sea.

11.2. GRID-CONNECTED RENEWABLE POWER SYSTEMS

Another way of using renewable electricity is to generate your own from on-site renewable systems.[6] This option depends upon the suitability of the location to construct an efficient renewable power system, and whether the electricity supplier/power grid operator allows power to be fed back into the grid. Ideally the amount of generating capacity should match the average amount of power consumed, although the cost, size and ability to dump excess power back into the grid are all factors in the planning and installation of grid-connected systems.

An important consideration in creating a grid-connected power system is cost. While developing a grid-connected renewable system is likely to be competitive with buying renewable electricity from the grid, it will never be a means to reduce the cost of electricity overall. That's because, even in those nations where electricity is very expensive, the cost of installing and maintaining small-scale grid-connected systems will be greater than the large economies of scale offered by large power grids. But, as noted above, if we wish to develop an alternative to the fossil-fuelled power grid then it is small, local and largely self-contained systems such as this (collectively called distributed generation)[7] which will be required to address our current demand for electricity.

Figure 11.1 shows a typical grid-connected power system. Electricity produced by one or more renewable generating technologies is supplied to a synchronising inverter. This converts the low voltage direct current (DC) of small renewable technologies into high voltage alternating current (AC) used by the power grid. This allows the locally generated power to flow into the system without generating interference with the power from the grid.

If the renewable power sources do not generate enough current the grid supplies the difference between what is being generated and what is being used. Where the local system produces more than required it is possible, if the grid operator allows it, to feed that excess power back into the grid. This is usually done by having two electricity meters. One measures the power used from the grid, while the other measures the power flowing back to the grid. When the utility company sends the bill they calculate the price of the power supplied to the grid and subtract that from the price of the power consumed (note, grid operators may not pay the same amount for the power you supply them as they charge for the power they supply to you).

Over the last two decades grid-connected renewable power systems have become popular in many states because they allow people to produce their own energy[8] without the problematic restrictions of being wholly cut off from the grid. In some European states governments pay a premium for the power produced,[9] and so the public can earn money from operating these systems in homes and businesses (they have become especially popular on rural farms where the large space available allows a much larger scale of installation). One difficulty that has arisen with these systems is that the synchronising inverter requires electricity to function. If the generating system produces insufficient power, or it's sited in a very poor location, the system can actually consume more electricity than it creates (this was a particular problem identified with small wind turbines designed for installation on rooftops in the UK).[10]

The problem with grid-connected renewable systems is that many of them do not function during a power cut. That's because the synchronising inverter requires the signal from the power grid to function – even if you are generating power, it will not be supplied to

6. For example, see Wikipedia: 'Grid-connected photovoltaic power system'. en.wikipedia.org/wiki/Grid-connected_photovoltaic_power_system
7. Wikipedia: 'Distributed generation'. en.wikipedia.org/wiki/Distributed_generation
8. Wikipedia: 'Grid-connected photovoltaic power system'. en.wikipedia.org/wiki/Grid-connected_photovoltaic_power_system
9. Wikipedia: 'Feed-in tariff'. en.wikipedia.org/wiki/Feed-in_tariff
10. Encraft (2009). Warwick Wind Trials. www.warwickwindtrials.org.uk

Box 11.2.

Uninterruptible power supplies

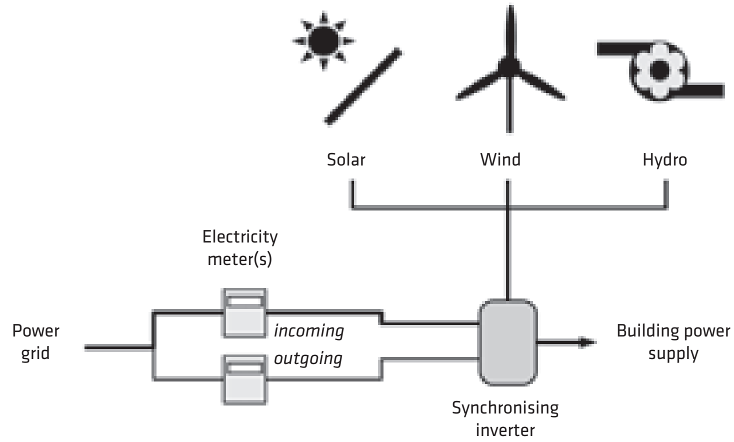
While not directly related to renewable energy, this is a topic of relevance to the provision of power to computers. Uninterruptible power supplies (UPS) are a means of protecting equipment against power cuts. For servers and small networks, especially when using a client-server network, a UPS protects against the data loss caused by small fluctuations or temporary interruption of mains power. In the most developed states, where the electricity grid has a very high reliability, UPSs are only used in large data centres and corporate networks – where high reliability is an essential part of the services provided. In less developed states, where brown-outs and temporary interruptions are more commonplace, the use of UPSs to prevent data loss can be more common – although often the costs of these units deters their wider use.

How expensive the UPS is depends upon how long you want it to function. The cheapest only provide a few minutes of power – just enough to enable the server/desktop to close down the running programs and prevent data loss, or to prevent small fluctuations in the supply interrupting the computer. More expensive systems use a large bank of batteries to provide power for longer periods, or have a small battery bank to keep the equipment running while a generator starts up to supply power.

If data loss from an unreliable power supply is a problem, using a UPS is often a good investment because of the time and data saved. However, for most small computer users having a UPS for a single desktop machine can be expensive it is more practical to use a laptop computer instead. The internal battery of the laptop will cover temporary losses of power just like a UPS, although you will have a problem if using other mains-powered printers and peripherals. Using a laptop is also better suited to off-grid power supplies, not only because of their greater efficiency but also because laptops run at low voltages which can be matched by most small, renewable-power systems.

Figure 11.1.

Grid-connected power system



the building. To get around this problem some systems incorporate battery storage, allowing them to keep the inverter running without a grid supply. In effect, they function like a large uninterruptible power supply for the whole building. Due to their greater complexity, these systems are more expensive to install and require more maintenance. Even so, if the reliability of the grid supply is an issue, grid-connected renewable generation can be a means of securing the power supply to the building in the event of the grid going down.

11.3. OFF-GRID RENEWABLE POWER SYSTEMS

An advantage of renewable power technology is that it allows the development of power systems well beyond the reach of the power grid.[11] This has obvious benefits for developing nations, and also for the use of mobile systems (for example, built into vehicles or vans) which allow ICTs to go on tour into rural areas. The critical factor in the design of an off-grid system is the average amount of power that needs to be supplied, and how long it must be supplied for. These two measures determine the amount of equipment required and thus the costs of the system.

Unlike the power grid, where more power can be supplied instantaneously on demand, the generating and storage capacity of an off-grid system has absolute limits to its use. In order to make the costs and scale of the off-grid power supply manageable, the equipment used must function as efficiently as possible. The cost of supplying each additional kilowatt-hour of power is greater than for mains-powered equipment, and adding more power generation or storage capacity to supply inefficient equipment represents an unnecessary expense. As a result, the cost of more expensive but efficient computers and other equipment can often be justified by the cost savings from the power saved.

Figure 11.2 shows a schematic of a typical off-grid power system. By examining this you should be able to understand how these

11. Wikipedia: 'Off-the-grid'. en.wikipedia.org/wiki/Off-the-grid

systems work. There are many companies producing systems such as this, and they will construct/install it in order to ensure its safe operation in accordance with national building and electrical codes. With a basic understanding of electronics, it's relatively simple to construct one from individual parts. Either way, in order to specify the size and performance of the installation it is necessary to have a basic grasp of the principles involved.

At the heart of the system is the battery storage.[12] Its capacity determines how much power the system can supply, and for how long. It's also the most significant hazard in the system. A battery is a reserve of potential energy. When supplied at the required rate that's quite safe, but if a major fault occurs that potential energy can be released almost instantaneously – creating both a fire and flash burn hazard. Guarding against this is a matter of system design, protecting against short circuits, power surges, etc; and mechanical good design, ensuring that the battery is housed in a suitable enclosure to protect it against physical damage, rain, frost, and heat.

Off-grid systems[13] operate at low voltages using direct current. A commercial system might use 24 volts or 48 volts, whereas most self-built systems will use 12 volts as this is the standard used in leisure/off-grid consumer systems. The voltage is a factor because it has an effect on efficiency – the higher the voltage, the more efficient the system. It is also important to consider the ease of maintaining and repairing the system – 24 and 48-volt components are relatively harder to source than the 12-volt units available through many outdoors and mobile home dealers.

There are a number of different battery technologies available, each with different costs and characteristics. The batteries used in cars and lorries are of low quality, and while they can be used to store power it's very inefficient to do so as they lose so much during charging, and can only be discharged by a small amount before cell damage occurs. Most batteries for power systems, while similar to automotive batteries, are more advanced "sealed" lead-acid batteries. These have a longer life, are more efficient to charge, and can use up to half of their rated capacity before battery damage occurs. There are a number of different types of deep-cycle battery, from the basic leisure batteries used in mobile homes, to more advanced industrial batteries used in uninterruptible power supplies, to the highly specialised gel batteries designed for use in solar PV systems. How well the system performs over its lifetime depends to a large extent on the type and quality of the battery technology used.

Which power source is used to charge the battery will depend upon the feasibility of each technology for the application chosen. Some technologies are relatively mobile while others are only viable on a fixed site. Another factor is power density – how much power can be produced with a given amount of space and equipment:

- Solar photovoltaic[14] (PV) panels are the simplest option. They're essentially a passive technology – you put them in the sunshine and they produce power.
- Wind power[15] is the next most dense source of energy. This is more complex to construct as it requires a tower to be erected.
- Hydro power[16] is the next most dense. The difficulty is that this requires the installation of pipework to tap a source of falling water – the greater the height the water drops, the greater the pressure in the pipe and the higher the power output.
- It is possible to use a generator powered by biofuel[17] or biogas. This is a heavier and more complex operation, but it represents a very dense source of power as gas and biofuel contain a lot of energy in a small volume of fuel.

The battery store has a fixed capacity. If the battery was continually charged past that point it would slowly degrade the battery, and in the worst case could lead to a fire or release of flammable gases. To protect against this

12. Wikipedia: 'Lead-acid battery'. en.wikipedia.org/wiki/Lead-acid_battery

13. For a general introduction see the Homepower Magazine website. homepower.com/basics/started/

14. Wikipedia: 'Photovoltaic system'. en.wikipedia.org/wiki/Photovoltaic_system

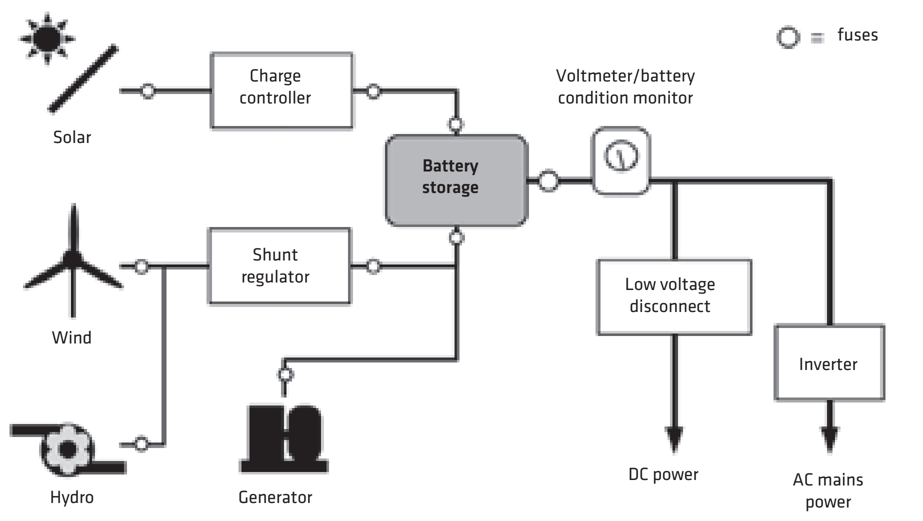
15. Wikipedia: 'Wind power'. en.wikipedia.org/wiki/Wind_power

16. Wikipedia: 'Microhydro'. en.wikipedia.org/wiki/Microhydro

17. Wikipedia: 'Biofuel'. en.wikipedia.org/wiki/Biofuel

Figure 11.2.

A typical off-grid power system



the battery must have a cut-out device which prevents overcharging:

- Certain power sources, such as solar PV, can be automatically disconnected to prevent overcharging. This is achieved with a voltage-controlled switch called a *charge* controller.[18] When the battery reaches full capacity its voltage begins to rise exponentially. As it rises above a set point the controller disconnects the panels. More advanced controllers for larger PV systems (half a kilowatt or greater) – *called maximum power point tracking controllers* – sense the optimum operating voltage of the solar panels and adjust according. This increases the efficiency of the system by 15% in summer and up to 30% in winter.
- Other power sources, especially wind and hydro, cannot be disconnected to prevent overcharging. For example, if you disconnected a wind turbine the resistance to the wind created by the battery is removed and the turbine would spin faster and faster until it ripped itself apart. In these cases a shunt regulator is used. Like a charge controller it senses the battery voltage, but instead of disconnecting it switches the current to a bank of high capacity resistors which dump the excess current as heat (in the most ecological designs, the excess power might even be used to heat water).

Note that many of the diesel/petrol generators[19] designed for use with batteries include over-charge controls as part of their design, and will gradually slow the engine to an idle tick-over once the battery is charged (more advanced models will automatically turn off and on in response to the change in battery voltage). If using a very basic generator without these advanced monitoring systems it should be connected to the battery using a charge controller. This will disconnect the load and the generator engine should automatically slow down to an idling tick-over.

At the simplest level, using the power stored in the battery involves connecting a load across the terminals. In practice it is more complex as you also need to monitor the battery condition to prevent it being over-discharged.

18. Wikipedia: 'Charge controller'. en.wikipedia.org/wiki/Charge_controller

19. Wikipedia: 'Engine generator'. en.wikipedia.org/wiki/Engine-generator

Just like over-charging, regularly exceeding the battery's discharge limit will cause damage. Most commercial off-grid systems have a single computerised controller. This monitors both the charging and discharge of the battery store, and gives a read out of how much energy is stored inside the battery. Self-built systems assembled from individual parts usually have a separate battery monitor – often no more than a voltmeter – and a low voltage disconnect unit. Just like a charge controller, this monitors the battery voltage and in the event it falls too far it disconnects the load to prevent damage to the battery.

The power from the battery can be used directly if the equipment functions at that voltage. As noted above, it's essential to use a low-voltage disconnect unit to protect the battery if you use the power directly. For devices which do not operate at the battery voltage you will need either a power regulator to drop the voltage down to the required level, or a power converter (sometimes called a "DC to DC" or "buck converter") to step-up the voltage to the required level. For example, most small self-built systems operate at 12 volts but most laptops use 18 to 20 volts. There are a number of power converters available on the market. Often these are designed for use in cars, and can be adapted to work with small battery-powered supplies.

Finally the battery's DC voltage can be converted into mains AC using a *power inverter*.[20] Some very expensive inverters can take any input voltage, but most inverters are designed to be used with a specific battery voltage either – 12, 24 or 48 volts. There are two general types of inverter:

- *Modified sine wave inverters* produce a very rough approximation of mains voltage. This means they are more efficient, but the modified sine wave can affect the operation of voltage sensitive equipment such as TVs and video recorders, data projectors and desktop computers. Mains lighting and many types of motor-driven equipment are usually unaffected.
- *Sine wave inverters* create a fully compatible mains supply, although doing this can use 30% to 50% more energy than using a modified sine wave.

If you are only using an inverter, a low-voltage disconnect is not usually required as most inverters include an automatic disconnect. However, when you buy the inverter you should always check the voltage at which the inverter's disconnect functions to ensure that it doesn't over-discharge the type of battery you are using.

For those without experience of electronics or mechanics all this may seem rather daunting. Even so, if you were to buy a commercially produced system the considerations and specifications that you need to answer to make a purchase would cover much of this same ground – although perhaps not in the detail explored here. Before moving on to build or use a much larger system, you might find it helpful to buy a small educational solar power kit. These use exactly the same system components, albeit with a fraction of the power capacity. This enables you to learn more about the design and construction of these systems, and to get a basic grounding in the principles of their operation, before you move on to constructing more large-scale systems.

It should be noted that, even with the best-designed off-grid system, there may be times when it simply runs out of power. That's the nature of renewable energy; it is variable, and occasional natural variation will challenge the assumptions made in the design of most systems. On these occasions we just have to accept that we do no work – *nature has given us a holiday and we should do something else which does not involve the consumption of electricity!*

20. Wikipedia: 'Power inverter'. en.wikipedia.org/wiki/Power_inverter

A practical guide to sustainable IT

This practical guide to sustainable IT offers a detailed, hands-on introduction to thinking about sustainable computing holistically; starting with the choices you make when buying technology, the software and peripherals you use, through to how you store and work with information, manage your security, save power, and maintain and dispose of your old hardware. Suggestions and advice for policy makers are also included, along with some practical tips for internet service providers.

Written by IT expert and environmentalist Paul Mobbs, the purpose of the guide is to encourage ICT-for-development (ICTD) practitioners to begin using technology in an environmentally sound way. But its usefulness extends beyond this to everyday consumers of technology, whether in the home or office environment. We can all play our part, and the practice of sustainable computing will go a long way in helping to tackle the environmental crisis facing our planet.

This is also more than just a "how to" guide. Mobbs brings his specific perspective to the topic of sustainable IT, and the practical lessons learned here suggest a bigger picture of how we, as humans, need to live and interact in order to secure our future.

The guide is divided into 12 sections (or "units"), with each unit building thematically on the ones that have come before. They can be read consecutively, or separately. The "unit" approach allows the sections to be updated over time, extracted for use as resource guides in workshops, or shared easily with colleagues and friends.

The guide has been developed on behalf of the Association for Progressive Communications (APC), with funding support from the International Development Research Centre (www.idrc.ca). It is part of a APC's GreeningIT initiative, which looks to promote an environmental consciousness amongst civil society groups using ICTs, and amongst the public generally. Other publications and research reports completed as part of the GreeningIT initiative can be downloaded at: greeningit.apc.org

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