TOM PAIVA PHOTOGRAPHY/GETTY

Wind turbines are low-density sources of power.

ENERGY

Profiles of power

Arnulf Grubler examines a study of power output and spatial area — a key concept in discussing renewables.

Vaclav Smil is a prolific, sometimes controversial, but invariably thought-provoking author. His latest book centres on a simple but important concept. Power density — defined in the book as "energy's rate of flow [transfer] per unit of surface area" of land or water — matters because these densities differ vastly for different methods of energy generation and use. That difference needs to be reconciled: massive, costly energy infrastructures such as long-range transport and storage are involved.

Megacities, with their concentrations of high-rise buildings, demand enormous quantities of energy in a comparatively small amount of space at any one time — and so have a high density of power demand. But diffuse renewable energy sources such as sunlight or biomass have low energy yields per hectare and intermittent availability, and so are low-density power supplies. Hence, in any transition towards renewables, cities will require vast renewable-energy hinterlands along with extensive cropland for food.

Smil excels when discussing the historical context of how our economy, cities and industry rose by harnessing high-power-density fossil fuels. He is also good at explaining the fundamentals that underlie the low power densities of renewables, such as the low efficiency by which plants convert the radiant energy of sunlight into chemical energy in the form of biomass (0.5%, Smil shows). Photos illustrate the energy options well.

However, Smil's technical discussion of options from renewables such as solar and wind to fossil fuels such as coal and gas, with its many site-specific examples, is necessarily repetitive and thus a tedious read. Moreover, he fails to clarify some fundamental concepts or to differentiate appropriately between different qualitative aspects of power and area.

Power Density: A Key to Understanding Energy Sources and Uses
VACLAV SMIL
MIT Press: 2015.

Most fundamentally, he does not explain the concepts of power and energy per se; he seems to presume that readers are familiar with them. And it is unclear why he focuses on power density rather than energy density, or does not combine the two (given that energy = power × time). Imagine a stream of water running at 1 litre per second. The total amount of water (86,400 litres a day) is the energy; the flow at any one moment is the power (1 litre). If you need more than the available flow, your power demand exceeds the power supply and cannot be met. If you dam and store the flow, then suddenly release it, you vastly increase the power; but you cannot increase the total energy.

In my view, the primary constraint is the total usable energy flow. The rate at which energy can be transferred (power) acts as a secondary constraint, particularly for renewables, because of their low energy density and intermittent availability. Conversely, a high power density does not necessarily translate into a high energy density. To illustrate: lightning has an electric power equivalent to the output of ten large nuclear power stations. But because it lasts for just a fraction of a second, it only provides enough energy to power an electric car for less than 1 kilometre.

The book also creates confusion because many of Smil's examples of power density are actually energy densities. He is aware that power density as a measure should not focus on brief bursts of extreme energy availability, such as the solar electricity generated at noon in southern Arizona; it should be averaged over a larger territory and longer periods. And he appropriately calculates average, representative power densities, expressed as watts per square metre ($W\,m^{-2}$). The standard unit for power, the watt, is defined as joules per second. But Smil's power densities are averages calculated over an entire year, and so become energy densities (in watt-years per year), an equivalence he fails to explain. However, he is not alone in this confusing use of power units that actually denote energy flows. Climate scientists also use $W\,m^{-2}$ to describe the radiative balance of the planet and its alteration by increasing concentrations of greenhouse gases.

There are also important qualitative aspects that need to be

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considered. It matters whether power refers to electricity or biomass. And it matters whether land is used exclusively or only partly for energy. Smil raises this issue but does not address it systemically. He could have used the concept of exergy (energy's ability to perform useful work) to differentiate between high-quality energy (such as electricity, which is versatile) and low-quality energy (such as straw, which demands costly conversions to become usable beyond burning). However, his comparisons look only at power densities, irrespective of quality. Smil sketches out a valuable taxonomy of energy-related land uses along two dimensions. The first is exclusivity: the site of a power plant, for instance, is unusable for agriculture; right-of-way land underneath transmission lines is not. The second is longevity of use: a nuclear-waste repository will be in place for centuries, whereas an annual crop such as maize (corn) for conversion to ethanol can be grown in rotation. Yet Smil does not use this taxonomy, and as a result sometimes compares 'apples and oranges'.

"Cities will require vast renewable-energy hinterlands."

Unlike in some of Smil's other books, the production quality of *Power Density* is regrettably low. I prefer readable graphics accompanied consistently by source and data referencing. In this book, many graph labels are hardly legible, and figures with references are the exception. Sometimes sources are mentioned in the text but not in the caption; at others, they are not even in the text. Graphs plot data on population and energy use, but statistical data sources are not specified or referenced.

Power Density's detailed examination of the spatial constraints of energy options adds to Smil's earlier, pioneering treatment of the subject, making it useful for energy specialists interested in exploring a massive ramp-up of renewables. But its technical nature and language make it rather inaccessible to a wider audience. And its failure to explain fundamental concepts such as the difference between power and energy, and to provide adequate data and source referencing, make it unsuitable as a textbook. ■

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HUMAN EVOLUTION

The cradle of humankind revisited

Michael Cherry catches up with new developments and old dilemmas at South Africa's hominin-fossil hotspot.

NATURAL HISTORY MUSEUM LONDON/SPL

Australopithecus sediba **was discovered at Malapa Cave in South Africa.**

I reach the Cradle of Humankind after half an hour's drive from Johannesburg, through the Gauteng Highveld of South Africa. This open, grassy space scattered with trees is a World Heritage Site, riddled with limestone caves and hominin fossils. A substantial chunk of the evidence that Africa is the wellspring of humanity was discovered here; and with anthropologist Lee Berger of the University of Witwatersrand (Wits) in Johannesburg set to unearth more at the Malapa and Rising Star Cave sites, the Cradle still rocks.

As a heritage site in a developing country, the area is a focus for national pride. But developments there are spurring questions over which part of the nation they serve.

Palaeontologists will rejoice over the launch, on 21 July, of a state-of-the-art vault to house star local finds, an adjunct to Wits's Centre of Excellence for Palaeosciences. The vault will allow specimens to be compared with other finds, both hominin and non-hominin, from around Africa. These include the Taung skull (*Australopithecus africanus*), dated to between 2 million and 3 million years ago, which was discovered north of Kimberley in 1924; specimens of *Australopithecus sediba* discovered at Malapa, including a remarkably complete skeleton called MH1, as well as casts of East African discoveries such as Lucy (*Australopithecus afarensis*) and the type specimen of *Homo habilis*, found by anthropologists Mary and Louis Leakey. The vault's laboratory has a micro-CT scanner and 3D printing facilities. But it is strictly for researchers' use.

What is there for the public? The Maropeng visitor centre opened a decade ago as an interpretation centre for the Sterkfontein Caves, site of the discovery of the 'Mrs Ples' fossil (*Australopithecus africanus*) in 1947 and, 50 years later, Little Foot, the most complete early-hominin skeleton known, which is as-yet undescribed. And late last year, a light, moveable, steel structure known as the Beetle was placed over the Malapa site to let the paying public view excavations, once they resume at the site. (Digging has been on hold since 2009, when the remains of four *A. sediba* individuals were removed.)

The Beetle protects the delicate limestone system from rain, and lets wild animals move freely below. Standing on eight clavicle-like supports, it has a fabric roof that collects rainwater and channels it to a sanitation system. Visitors will watch excavations from a raised circular walkway. A pulley below the platform is attached to a hoist capable of bearing a tonne of rock.

But there are questions over how 'public' the Beetle actually is. Costing half a million US dollars — paid for largely through the National Research Foundation (using taxpayers' money), as well as Wits and the Gauteng provincial government — the site is in a private game reserve and the tourists, when they come, will probably be rich. The Maropeng centre demonstrates this. Built at a cost of US$29 million, it charges $13 for admission (around half that for students), which prices out many in a country where one-fifth of the people still live on $28 a month. That could be reflected in Maropeng's visitor numbers. Planned to accommodate 1 million visitors a year, it receives between 230,000 and 250,000 and runs at an annual loss, picked up by the provincial government. Kruger National Park, by contrast, charges different rates for South Africans and foreign tourists, and receives 1.4 million visitors annually.

Remarkable fossils continue to emerge in the Cradle, and it presents no less remarkable opportunities for palaeotourism. But a way must be found to make the specimens widely accessible. *In situ* interpretation of australopithecine remains should present a uniquely uplifting experience for all, rich and poor. ■

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