The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach

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1. Introduction

1.1. Disruptive technologies and future energy demand

The future of energy is widely studied and discussed in business, academia and politics, and scenario building is often used in these studies and discussions. However, the effect of emerging technologies – such as additive manufacturing (AM), big data, robotics, the Internet of Things and autonomous driving – on the future energy consumption is often overlooked. Even long-term energy scenarios and normative visions are usually based on familiar technologies, directly related to the energy industry. This gap may result in energy policymakers stimulating only traditional sectors rather than also looking at adjacent areas of innovation that can be extremely effective in reducing energy demand while matching important co-benefits (Nagji and Tuff, 2012).

In an effort to close this gap, this article presents a bottom-up assessment of the potential effect of one such disruptive technology, namely AM, on the global energy demand in 2050. AM was chosen because it is disruptive and paradigm changing for manufacturing, logistics, product design, intellectual property, local production and mass customisation.

1.2. Additive manufacturing

Additive manufacturing, popularly known as 3D printing, is the process of building objects bottom-up, one layer at a time. AM is an umbrella term for a group of technologies (Cottelee, 2014). Table 1 and Fig. 1 present overviews of AM processes along with the related technologies and the materials used. As can be seen, the range of techniques and materials is extensive. Traditional subtractive manufacturing techniques build objects by cutting or machining raw materials into the desired shape, after which several objects are assembled to form the final product. Other mass production techniques, such as injection moulding and metal stamping, produce less waste but require large production volumes.

3D printing involves three essential phases (Campbell et al., 2011). First, a digital 3D model is designed and converted into a standard AM format file. Second, this file is sent to the 3D printer, where it is...
Table 1
Overview of additive manufacturing processes, the materials used and the technologies involved (Manyika et al., 2013; DOE, 2015).

<table>
<thead>
<tr>
<th>AM process type</th>
<th>Brief description</th>
<th>Materials used</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder bed fusion</td>
<td>Thermal energy selectively fuses regions of a powder bed</td>
<td>Metals, polymers</td>
<td>Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), direct metal laser sintering (DMLS)</td>
</tr>
<tr>
<td>Directed energy deposition</td>
<td>Focused thermal energy is used to fuse materials by melting as the material is being deposited</td>
<td>Metals</td>
<td>Laser metal deposition (LMD)</td>
</tr>
<tr>
<td>Material extrusion</td>
<td>Material is selectively dispensed through a nozzle or orifice</td>
<td>Polymers</td>
<td>Fused deposition modelling (FDM)</td>
</tr>
<tr>
<td>Vat photo polymerisation</td>
<td>Liquid photopolymer in a vat is selectively cured by light-activated polymerisation</td>
<td>Photopolymers</td>
<td>Stereolithography, digital light processing (DLP)</td>
</tr>
<tr>
<td>Binder jetting</td>
<td>A liquid bonding agent is selectively deposited to join powder materials</td>
<td>Polymers, foundry sand, metals</td>
<td>Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)</td>
</tr>
<tr>
<td>Material jetting</td>
<td>Droplets of build material are selectively deposited</td>
<td>Polymers, waxes</td>
<td>Multi-jet modelling (MJM)</td>
</tr>
<tr>
<td>Sheet lamination</td>
<td>Sheets of material are bonded to form an object</td>
<td>Paper, metals</td>
<td>Laminated object manufacturing (LOM), ultrasonic consolidation (UC)</td>
</tr>
<tr>
<td>Inkjet-bioprinting</td>
<td>A nozzle deposits tiny dots of a combination of scaffolding material (e.g. hydrogel) and living cells</td>
<td>Biomaterials, human cells</td>
<td>Inkjet-bioprinting</td>
</tr>
</tbody>
</table>

Fig. 1. Overview of additive manufacturing (3D Printing) technologies and the materials used, displaying the wide range of techniques and materials.
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