

## Article

# A Holistic Framework for Developing Expert Systems to Improve Energy Efficiency in Manufacturing

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**Abstract:** Amid growing environmental and societal concerns about energy use, companies face increasing pressure to adopt sustainable manufacturing practices. The European Union's guiding principles, aimed in part at achieving climate neutrality and fostering green growth, underscore the need for systematic, data-driven approaches to energy efficiency. This involves the measurement, monitoring, and analysis of energy data. However, identifying efficiency potentials often relies on expert knowledge, which is becoming increasingly scarce due to skilled labor shortages. Expert systems offer a solution by consolidating and analyzing data to automatically identify energy-saving opportunities. These systems leverage stored expertise, applying it to measurement data to generate actionable insights, while their explicit knowledge representation and transparent reasoning facilitate knowledge transfer. Despite their potential, most expert systems are developed intuitively and tailored to specific applications, limiting their broader adoption. To address this, we propose a holistic framework for systematic expert system development, supported by defined personas and an expert system shell serving as a software template. The framework is demonstrated and evaluated through its application in a metalworking process chain.

**Keywords:** sustainability; knowledge-based system; energy management; energy analysis; knowledge management; fuzzy reasoning



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## 1. Introduction

Climate change poses a significant global challenge, threatening ecosystems, economies, and societies alike. In response, the 2015 Paris Agreement set the target to limit global warming to 1.5 °C, aiming to mitigate the risks of extreme weather events and irreversible tipping points [1]. This goal necessitates coordinated and effective actions at both national and international levels. The European Union (EU) has positioned itself as a global leader in climate action, with its European Climate Law mandating a reduction in greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels [1]. This commitment underscores the EU's pursuit of climate neutrality by 2050 as part of its broader Green Deal agenda [1]. Germany, as the world's third-largest economy and the largest in the EU (by gross domestic product) [2], has historically contributed approximately five percent of global warming-related emissions since industrialization [3] and therefore bears particular responsibility for climate action. Consequently, Germany has responded by committing to ambitious greenhouse gas emission reductions of 65% through its Federal Climate Action Act [4]. This effort aligns closely with the EU's broader objectives.

Central to these efforts is the industrial sector, a cornerstone of the EU and Germany's green transitions. In Germany, it is the second-largest source of energy-related greenhouse

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