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Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society

Torbjörn Rydberg [a,*], Andrew C. Haden [b]

[a] Centre for Sustainable Agriculture, Swedish University of Agricultural Sciences, P.O. Box 7047, SE-75007 Uppsala, Sweden
[b] Department of Rural Development and Agroecology, Swedish University of Agricultural Sciences, P.O. Box 7005, SE-750 07 Uppsala, Sweden

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Abstract

This paper presents emergy evaluations of Denmark and Danish agriculture for the years 1936, 1970 and 1999. The evaluations highlight the changing relationship between agriculture and society over the time period studied. A large increase in total emergy supporting the Danish economy was observed, and the 379% rise from 1936 to 1999 in emergy use per capita, a biophysical measure of living standard, came from both imported sources and from the non-renewable storages of the biosphere. In 1936, Danish agriculture was largely based on the use of draft animals for traction and approximately 1,110,000,000 person-hours of direct labor were required for production, while in 1970 and 1999, all traction was mechanized and approximately 415,000,000 and 121,000,000 person-hours were required for production, respectively. Over the same period, the emergy supporting each person-hour of agricultural labor increased by 1600%. The driving forces for agricultural production shifted towards an increased reliance on commercial energy and indirect labor. Given the increase in emergy available to the Danish economy through extraction and use of domestic oil and gas and trade over the period studied, the shift in labor from agriculture to the service and manufacturing sectors represented a nation-wide re-organization for maximum empower. The evaluations also indicate that while agriculture remains an essential way for industrial economies to capture local renewable resources, given the limited net emergy yields of agricultural production, the magnitude of non-agricultural economic activity that agriculture systems can support appears limited in an economy with access to high-net-yield imported energy resources.

Keywords: Emergy evaluation; Ecological sustainability; Empower; Industrial agriculture; Agricultural labor

1. Introduction

Agriculture is a primary activity by which human societies channel contemporary renewable energy flows into products that support societal welfare. For millennia, the agricultural systems of the world were run on locally available materials and renewable energy sources, and supported societies with complex, locally adapted economic, cultural and knowledge systems—albeit in a world with far fewer people than today (Odum, 1971; Pimentel and Pimentel, 1979). Over the past century, agricultural systems, agricultural technology and the socioeconomic structures to which they are coupled have undergone a dramatic transformation, and this transformation has been especially pronounced in the industrialized and newly industrializing regions of the planet (Cleveland, 1994; Conforti and Giampietro, 1997; Björklund et al., 1999). Salient among the observed trends during the era of rapid industrialization in agriculture has been a dramatic increase in commercial energy use in agricultural production, a no-less dramatic decrease in direct labor requirements, and a substantial increase in gross productivity per unit labor and per unit area. For these trends to be placed within their proper

* Corresponding author. Tel.: +46 18 672911; fax: +46 18 673571.
E-mail address: torbjorn.rydberg@evp.slu.se (T. Rydberg).

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historical context, they must be understood as an outgrowth of the ability of human society to harness and utilize more concentrated, higher quality energy sources (Odum, 1971; Hall et al., 1986; Adams, 1988). In broad terms, this history represents a shift in the energetic resource base of society from solar energy, in the form of food and wood, to coal, and then oil, natural gas, hydroelectric and nuclear energy as the main driving forces behind economic growth and societal development. This long-term and relatively constant expansion and diversification of the 'energy signature' of industrial societies has strongly influenced the organization of their agricultural systems, and the relative abundance and diversity of energy sources available to the industrialized world continues to influence perceived options for the future direction for agriculture and rural development in industrialized nations.

Given that inexpensive petroleum energy resources will not be available indefinitely, at current rates of use and proved reserves (Campbell and Laherrère, 1998; Deffeyes, 2001), society will eventually be forced to make choices regarding how to invest what remains of this important commodity. Perhaps because it entails the investment of some high quality non-renewable energy to capture a lower quality yet more abundant quantity of renewable energy, the use of petroleum resources to increase agricultural productivity has heretofore seemed a 'wise-use' policy. However, dwindling fossil fuel availability will undoubtedly force all uses of petroleum and its derivatives to fall under increased scrutiny. Thus, the development of decision-making tools for energy resource allocation may become a central task for science in the coming decades. In this paper, we use emergy evaluations and energy systems theory to explore the potential of agricultural systems to support industrial society using the example of Denmark. By presenting emergy evaluations of Denmark and Danish agriculture for the years 1936, 1970 and 1999 we show how the organization of Denmark's agricultural system responded to changes in the emergy use of the national economy to which it is nested, and examine the changing role of agriculture in the Danish national economy, in emergy terms. We suggest that, during an era of declining non-renewable resource availability, a power maximizing strategy could entail holding constant the ratio of emergy contributions to agricultural production from human labor (both direct and indirect) and physical resource emergy. A hypothesis requiring further investigation.

1.1. Emergy evaluations of agricultural systems

Agricultural science has primarily been concerned with increasing crop yields and improving the economic efficiency of individual farming systems and farming regions. This process has been characterized by finding new uses for machinery and fossil energy and its derivatives in agricultural production, and by a continual decrease in the direct human labor requirements for agriculture (Hall et al., 1986; Mayumi, 1991; Cleveland, 1994; Giampietro and Pimentel, 1991). When the outcomes of this process are gauged against the performance indicators of gross yield and economic efficiency, agricultural science and engineering has been very successful, and food has become both cheaper and more plentiful in many parts of the world (Conway, 1997). However, economic and gross yield assessments of agricultural productivity have often overlooked important parallel developments. Central among these correlated trends are the decline of net-energy yields (often measured as the food energy produced to the commercial energy invested) of modern agricultural systems relative to earlier, pre-industrial systems (Odum, 1967; Martinez-Alier, 1987; Fluck, 1992). This fact has led many to question the validity of modern agriculture's claims to superior efficiency; a claim often supported by measurements of productivity per unit labor, and not based on analyses of energy return on energy invested (Odum, 1984; Hall et al., 1986; Fluck, 1992).

Emergy evaluations join the long history of energy analysis of agricultural systems (see Martinez-Alier, 1987). However, emergy analyses may offer a more complete picture of agriculture's role in the biosphere and human economies by calculating the total work contributed by both natural and economic systems to generate agricultural products, measured on a common basis and in one kind of energy. Emergy evaluations thus provide a more universal assessment of the total work requirements of agricultural production than other methods that focus solely on commercial energy inputs, or which omit environmental energies or societal energy support for labor (often called 'lifestyle energy') (see Fluck, 1992). From its origins in ecosystem science, emergy analysis has evolved into an environmental assessment tool grounded in the laws of thermodynamics that offers a biophysical alternative to economic analysis (Odum, 1996). A primary strength of emergy evaluations is that it allows for processes producing similar products, but through different means, to be compared on a common basis. For example, Brown and Ulgiati (2002) compared electricity production from coal, oil, hydro-electricity, geothermal and wind turbine technologies to assess their renewability, efficiency, net yield to society, and environmental load, using emergy as a common metric.

Although emergy analysis is still a relatively new field of science, it is based on a steady progression of scholarship initiated by Howard T. Odum and colleagues beginning in the 1960s. Initial research began with the measurement of the flow of energy in ecosystems. This yielded insights into the general energy principles underlying ecological-economic systems, which in turn fostered expanded application to include agroecosystems and economic systems (Odum, 1967, 1971, 1988, 1994, 1996; Hall, 1995). Having evolved from ecological energetics, emergy analysis applied to agriculture can identify those farming systems that are more efficient at capturing and utilizing sunlight energy and its