Assessing Alternative Developments for Milk Production in the Southern Region of Minas Gerais State, Brazil: an Emergy Perspective

Max Wilson Oliveira and Feni Agostinho

ABSTRACT
Milk and its derived products are recognized as essential items in the human food chain. Brazil accounts for about 5% of the world production, 27% of this total is produced at the state of Minas Gerais, where diverse milk production systems prevail, thus differing on handling, productivity, rural property area, and dependence on economic resources. Rather than a purely economic view, sustainability issues have been more and more taken into consideration when it comes to any decision making related to public policies at local and regional perspectives. Regarding the second perspective, emergy accounting arises as a powerful methodology providing subsidies for a landscape planning under a holistic view. In this sense, this work aims to evaluate a regional alternative for milk production development on the southern region of Minas Gerais State, Brazil. Data from 92 milk producing properties are taken into consideration in establishing the five representative system groups (G1 to G5) under a non-parametric statistical approach (cluster). A Monte Carlo analysis is used for evaluating the uncertainties related to unit emergy values. Results show that the identified G3 milk production group features a higher sustainability level than other all groups (%R at 24%; EYR at 2.03; EIR at 0.97; ELR at 3.06; ESI at 0.66), but its emergy efficiency is the lowest one (1.68E+13 seJ/Lmilk). Regarding the regional analysis under a holistic view, the assessed emergy matching criteria could be considered as the alternative to be adopted, reducing the dependence on economic resources from 17.40 to 6.76E+21 seJ/yr to reach a balanced emergy inputs and an unitary EIR index.

INTRODUCTION
Cow milk, a source of protein, vitamins, minerals and energy is amongst the most consumed food items worldwide. Brazil currently holds the fourth position in the world milk production ranking, accounting for 5.3% of the overall production, after the United States (14.7%), India (8.6%) and China (6%) (FAO, 2013). Milk is produced virtually nationwide, employing nearly three million workers along its production chain. Economically, milk is among the six most important products from the national farming (CEPEA, 2012).

Despite being a great milk-producing nation, Brazil fares low productivity per animal at approximately 1380 Lmilk/cow/yr. According to Zoccal and Carneiro (2008), such low productivity results from the fact that most production systems belong to the so-called extensive type, by which the animals (most of which having low genetic potential for milk production) are fed hay and degraded pasture, exclusively. Intensive systems do exist in the region as well, and they are characterized by high productivity, mostly due to the use of modern technologies, concentrated feed, and specialized cattle for milk production; those, however, are found in much smaller quantities, as compared to the existing extensive ones.

The state of Minas Gerais is the number one milk producer in Brazil, accounting for 27% of the total national production (IBGE, 2012), however, that is a region where the extensive system prevails, as it does throughout the nation. Aiming to increase milk productivity in the region - consequently
improving the socio-economical aspects involved - the state government of Minas Gerais put forward the "Minas Leite" (Minas Milk) program in 2005, by which the so-called extensive producers can obtain technical training ranging from pastures treatment to business management, including furthering energy and materials supply for the intensification of the system. Thus a new milk production scenario rises in the southern part of the state, where the extensive production can be replaced by a more profitable one, causing social-economical and energy-environmental changes. Such scenario raises questions: which of the existing milk production systems in the south of Minas Gerais is most sustainable? What is the best alternative for the development of milk production in the region?

In attempting to provide answers to these questions, the emery environmental accounting (Odum, 1996) is suggested as a useful methodology due to its holistic approach, where the "quality" of different kinds of energy hierarchy is recognized. Emery assessment has been applied to studies on milk production systems sustainability, e.g., Rótole et al. (2010) studied the milk production on a farm in Argentina, Alfaro-Arguello et al. (2010) assessed farms in Mexico where both conventional and holistic systems were used, and more recently, Vigne et al. (2013) evaluated different systems in Mali, France and on Reunion Island. On the other hand, besides assessing different systems from those found in Brazil, those studies did not exploit regional development alternatives for milk production.

This study aims to (i) assess the sustainability of the existing milk production systems in the southern region of Minas Gerais, and (ii) exploit alternatives for the development of milk production in the region, focusing on efficient emery use and empower. Emery environmental accounting is used for the calculation of the traditional indexes which evaluate systems' sustainability, and the use of the Emery Investment Ratio (EIR) index as a parameter so as to verify which economical-environmental interface combination is the most sustainable for the region.

**METHODOLOGY**

**System geographical location and characterization using cluster approach**

The southern region of Minas Gerais state, Brazil (Figure 1) comprises 118 cities within a 3.7 million hectares total area. The region was selected as a case study due to the fact that the state of Minas Gerais accounts for approximately 27% of the milk production in Brazil, and the southern part of the state is where such production is concentrated. Primary data were collected in situ by considering 92 milk production systems, randomly distributed throughout the region, ranging 49 cities from a total of 118.

Several milk production system types exist in the region, featuring different productivity indexes, handling methods, intensity of labor, and use of energy and external materials. Based upon animal productivity and the technological level available, EMBRAPA (2005) – a major agricultural research

![Figure 1. Geographical location of the Southern region of Minas Gerais State, Brazil.](image-url)
center in Brazil – classifies milk production systems into four main types: (i) extensive system: per animal productivity below 1,200 L/year with animals raised exclusively by grazing; (ii) semi-intensive system: per animal productivity between 1200 e 2000 L/year, graze-raised with supplementary volume during dry pasture periods; (iii) pasture intensive system: 2000 to 4500 L/year productivity, graze-raised with high nutritional quality forage and supplementary volume throughout the year, or part of it; (iv) confinement intensive system: per animal productivity above 4500 L/year, trough-fed and full confinement.

As detailed as such classification can be, during the field-work period for collection of primary data, an operational difficulty was faced in clearly framing the production units into the four types defined above. Thus, the call for a cluster analysis was identified. For that purpose, the production systems were re-classified into three types only: (i) extensive system: cattle raised in pasture, with supplementary forage in times of dry pastures; (ii) semi-intensive system: cattle raised in pasture with supplementary volume and forage throughout the year; (iii) intensive system: total confinement, feeding based on ration and forage throughout the year. Such new classification was validated in common agreement with the technical staffs of “Instituto Mineiro de Agropecuária” (IMA), “Empresa de Assistência Técnica e Extensão Rural do Estado de Minas Gerais” (EMATER), and the regional dairy industries.

After reclassification, the following indicators were considered for the Cluster analysis: (i) Lmilk/ha/yr; (ii) Lmilk/labor-hours/day; (iii) Lmilk/cow/day; (iv) livestock/ha pasture; (v) kWh/Lmilk/yr; (vi) kg feed/Lmilk/yr; (vii) Cattle breed. The add-in “Action 2.5” (www.portalaction.com.br) for Microsoft Excel® was used for clustering analysis. Rather than calculating average values for each obtained clustering group, a single and representative milk production property was chosen as a reference by considering the Lmilk/cow/day indicator as a criterion; for that to be achieved, the property featuring the productivity which was closest to the average productivity was selected as the referential one for the cluster group. Such approach was assumed so as to avoid establishing a “hypothetical” system.

**Environmental accounting**

**Energetic evaluation procedure**

In this work, emergy synthesis is used in accordance to methodological procedures present in Odum (1996) and Brown and Ulgiati (2004), however considering the partial renewability of labor and water inputs as discussed, for instance, in Agostinho and Ortega (2012). The origin of labor inputs in milk production systems is local; moreover, the workers have a lifestyle of low intensity in energy and materials usage. Thus, this kind of labor should not be considered as fully non-renewable. The emergy renewability index of Brazil (15% according to Sweeney et al., 2007) is considered as the minimum partial renewability value of labor, and the 50% - authors’ assumption – is considered as maximum for the Monte Carlo analysis. Regarding water input (subterranean), the assumed range for partial renewability is from 50% to 85% - this range is in accordance with authors’ first estimation on the annual regional watershed charge volume.

The following traditional emergy indices as found in Odum (1996) and Brown and Ulgiati (2004) were considered in this work: renewability (%R), emergy yield ratio (EYR), emergy investment ratio (EIR), environmental loading ratio (ELR), and emergy sustainability index (ESI). However, the %R and ELR were modified by including the partial renewability of emergy flows as described above. Thus, these two modified indices from their traditional form becomes: m-%R (Modified Renewability index)=100*[(R+Mr+Sr)/Y] and m-ELR (Modified Emergy Loading Ratio)=(N+Sn+Mn)/(R+Sr+Mr).

Recognizing the importance of assessing uncertainties in emergy evaluations, a Monte Carlo simulation is used by randomly varying the Unit Emergy Values (UEVs) range borrowed from emergy literature, as well as the partial renewability of water and labor inputs as described above. Then, the emergy indices are calculated for the milk production system groups previously identified through clustering analysis; an index-to-index comparison for the system groups is made. Figure 2 is a scheme of the calculation procedure.
Figure 2. Scheme of emergy indices calculation procedure. Monte Carlo simulation is performed by using an Excel® add-in (Barreto and Howland, 2006) and assuming a uniform probabilistic distribution function under 10,000 interactions.

Evaluating alternatives for development

Odum (1996) hypothesize that the best use of emergy flow for maximizing production comes when the emergy feedback (F) to production matches the [indigenous] input emergy (I); matching emergy inflows to production is equivalent to balancing potentially limiting factors, resulting in an Emergy Investment Ratio (EIR=F/I) equal to 1. Thus, emergy is efficiently used when applied equally to both inputs “F” and “I”. However, according to maximum empower principle, systems that prevail are those that produce more emergy and utilize it more efficiently. Considering the current cheap oil availability, the displacement of primitive systems by the most economic ones is consistent with the empower principle. In this sense, Odum and Odum (2003) hypothesize that an area with economic uses at low EIR may not be able to maintain this development pattern because the potential for economic growth is large, and more intensive developments can displace the less intensive ones by drawing in more emergy and money. Thus, “to be sustainable, an ecological engineering interface should have an investment ratio similar or less than other environmental uses in the region. Systems with higher ratios are too costly to compete”. In short, when evaluating alternatives for development, the EIR of systems should match the regional EIR.

In Chapter 9 of Odum’s (1996) book, it is proposed two main alternatives for development: (i) emergy of alternative development in which the intensity of development is focused; (ii) emergy of potential matching, in which the economic matching is focused. The first one attempt to manage the system’s “I” input while the second approach focus on the “F” input. Considering the inherent difficult in managing the natural renewable resources represented by the “I” input – e.g. improving the amount of rainfall going into the system –, the emergy of potential matching is considered in this work when assessing the regional potential for milk production. For this, it is considered (i) the original development, (ii) the alternative development proposed by government in which the less intensive systems are replaced by the most intensive ones, and (iii) the regional potential based on the regional EIR under the economic matching approach.

RESULTS AND DISCUSSION

Milk production systems characterization from cluster analysis

Table 1 shows the defined milk production systems – or groups as labeled here – resulting from clustering approach. The number of groups was established by the authors who used their knowledge on the different existing systems in the region as a criterion. As expected, the G3 group comprises 48 properties from the 92 total and represents the lowest intensity milk production in the region. G3 is
Table 1. Clustering approach result. Groups and their milk production systems, average for group milk productivity, and the milk production system representative for the entire group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Classification</th>
<th>Milk production systems</th>
<th>Average for ( L_{\text{milk/cow/day}} )</th>
<th>System chosen as representative for the group*</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Semi-intensive</td>
<td>77</td>
<td>21</td>
<td>77</td>
</tr>
<tr>
<td>G2</td>
<td>Semi-intensive</td>
<td>47, 48, 49, 52, 53, 54, 56, 57, 58, 59, 60, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 73, 74, 75, 76, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>G3</td>
<td>Extensive</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 50, 51, 55</td>
<td>5,5</td>
<td>46</td>
</tr>
<tr>
<td>G4</td>
<td>Intensive</td>
<td>88, 89, 90</td>
<td>20</td>
<td>88</td>
</tr>
<tr>
<td>G5</td>
<td>Intensive</td>
<td>91, 92</td>
<td>32</td>
<td>91</td>
</tr>
</tbody>
</table>

*G1, system 77: 290 ha, 4,400 \( L_{\text{milk/day}} \), 21 \( L_{\text{milk/cow/day}} \); G2, system 60: 26 ha, 360 \( L_{\text{milk/day}} \), 12 \( L_{\text{milk/cow/day}} \); G3, system 46: 19 ha, 33 \( L_{\text{milk/day}} \), 5.5 \( L_{\text{milk/cow/day}} \); G4, system 88: 23 ha, 1,060 \( L_{\text{milk/day}} \), 20 \( L_{\text{milk/cow/day}} \); G5, system 91 (property 91 was chosen because it is more representative than 92): 130 ha, 3,500 \( L_{\text{milk/day}} \), 32 \( L_{\text{milk/cow/day}} \).

closer followed by group G2 with 35 properties and representing the semi-intensive milk production systems, i.e. it produces more by demanding more energy. G1 represents a semi-intensive system, however it is a special system due to its high productivity and it is rarely found in Brazil. G4 and G5 represent intensive systems, G5 being the most productive one. After clustering, instead of establishing an average value to define a hypothetical representative system of each group, the productivity in \( L_{\text{milk/cow/day}} \) was used as the criterion in selecting the actual representative system. In short, Table 1 shows that properties 77, 60, 46, 88 and 91 were chosen as representative for G1, G2, G3, G4 and G5 groups respectively.

**Emergy synthesis of milk productions groups**

Figure 3 represents the energy diagram for all five milk production groups assessed in this work. A single diagram is considered to represent all groups because all have similar characteristics as for energy and material inputs and outputs, differing basically on the amount of resources inflowing to the system. The most evident differences among the intensive system (G3) and the semi-intensive ones (G1 and G2) are in bold type in the diagram, e.g., the use of pickets (for rotational grazing) in the pasture lands, the demand for high genetically potential semen, the use of ration as feed supplement, automatized milking, and improvements in accounting-managerial questions; all such features are present in the semi-intensive systems, which results in productivity increase, as compared to the extensive system. The intensive systems feature the same characteristics mentioned, except that the animals are totally confined, therefore the pasture - colored gray in the diagram - is not assigned to groups G4 and G5 as the animals are exclusively ration-fed.

The emergy indices obtained for the five milk production groups studied are show in Table 2. Raw values for inputs as well as for the UEVs used are not presented due to the reduced available space - all raw data are being considered for publication at a scientific journal and could be seen after published.
As expected, considering a holistic view under emergy accounting, the G3 group can be considered as the most sustainable among all, because: (i) it has higher renewability (24.64%), (ii) higher emergy yield (investing one seJ from economy yields 2.03 seJ), (iii) lower emergy investment (each seJ from nature invested demands 0.97 seJ from economy), (iv) moderate environmental loading of 3.06 (between 1 and 4 range as suggested range by Brown and Ulgiati, 2004), (v) better sustainability index among all systems, although the 0.66 value represents a non-sustainable system according to Brown and Ulgiati (2004). On the other hand, due to G3 lower milk productivity, its efficiency in converting the input emergy into milk product is the lowest among all systems (1.68E+13 seJ/L milk).

**Table 2.** Emergy indices for the five different milk production systems present on the southern region of Minas Gerais State.

<table>
<thead>
<tr>
<th>Emergy index (^a)</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
</tr>
</thead>
<tbody>
<tr>
<td>m-%R</td>
<td>8.79</td>
<td>12.36</td>
<td>24.64</td>
<td>3.07</td>
<td>3.47</td>
</tr>
<tr>
<td>EYR</td>
<td>1.19</td>
<td>1.24</td>
<td>2.03</td>
<td>1.08</td>
<td>1.09</td>
</tr>
<tr>
<td>EIR</td>
<td>5.27</td>
<td>4.24</td>
<td>0.97</td>
<td>13.13</td>
<td>11.70</td>
</tr>
<tr>
<td>m-ELR</td>
<td>10.37</td>
<td>7.09</td>
<td>3.06</td>
<td>31.59</td>
<td>27.85</td>
</tr>
<tr>
<td>ESI</td>
<td>0.11</td>
<td>0.17</td>
<td>0.66</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Y (seJ/ha/yr)</td>
<td>3.13E+16</td>
<td>2.60E+16</td>
<td>1.17E+16</td>
<td>1.18E+17</td>
<td>8.25E+16</td>
</tr>
<tr>
<td>UEV (seJ/L milk)</td>
<td>3.55E+12</td>
<td>3.76E+12</td>
<td>1.68E+13</td>
<td>6.75E+12</td>
<td>6.39E+12</td>
</tr>
</tbody>
</table>

\( m-%R \) (Modified Renewability index) = 100\(^{\text{\%}}\)\((R+M_r+S_r)/(R+M_r+S_r+S_n)\); EYR (Emergy Yield Ratio) = \(Y/F\); EIR (Emergy Investment Ratio) = \(F/(R+N)\); m-ELR (Modified Emergy Loading Ratio) = \((N+S_n+M_n)/(R+S_r+M_r)\); ESI (Emergy Sustainability Index) = EYR/ELR; Y = system yield; UEV (Unit Emergy Value) = \(Y/\text{system output}\).
Establishing a winner system is not so easy, because rarely there is a system which has an evidenced better performance for all indices. However, trying to establish a sequential order regarding sustainability at long-term for all five groups studied, the following order is justified: G3 is most sustainable than G2 which is closer followed by G1, and much more sustainable than G5 and G4 (these two last have very similar emergy performance). It is worth to note that G1 and G2 are the most efficient in converting emergy inputs into milk output.

Assessing regional alternative development for milk production

Figure 4 represents the three arm diagram of the southern region of Minas Gerais State. Values show a dependence on “R” resources of 9.15E21 seJ/yr, a value 1.7 and 5.7 times higher than “F” and “N” resources respectively. These numbers result in an Energy Investment Ratio (EIR) of 0.50, a value not so far from the Brazilian EIR (0.36; Sweeney et al., 2007) and to the Minas Gerais State EIR (0.08; Demétrio, 2011). For each solar emjoule from the “I” source used by region, it is necessary about 0.5 solar emjoules from “F”; this is a characteristic of undeveloped regions when considering the fossil energy dependence as criteria, or a high industrialized region that produce the majority of its own resource needs. According to author’s knowledge of regional characteristics, the first premise represents the studied region.

The governmental intention of replacing primitive milk production systems (G3) by the more economic ones (G2) is consistent with the maximum empower principle (see empower values in Table 2) provided there are available sources of cheap emergy to purchase, basically fossil emergy. On the other hand, when exploring alternatives for development considering not exclusively the empower, but also the efficiency in emergy use under a regional perspective, the figures do change somewhat. Figure 5 shows four different alternatives for milk production development by taking these aspects into account, and the interpretation is as follows:

(a) Original: The current milk production in the region is based on unsustainable management, because it depends on higher amount of “F” than “I” resources, resulting in an EIR of 2.57. This uneven emergy inflow results in an EIR ratio higher than the regional average of 0.5 as shown on Figure 5. Within a short-term, this development pattern for milk production can prevail when compared to the primitive systems (e.i., the more ecological ones with lower dependence on “F”), however, when the “F” resources become expensive and/or unavailable due to fossil fuels shortage, such scenario could break down and reduce its intensity.

(b) The “Minas Leite” alternative: The governmental intention for milk intensification is represented in this scenario by replacing all the G3 systems by the G2 systems. This scenario can be considered as a worse alternative than the Original one. The “Minas Leite” alternative is unsustainable due to the increase in “F” dependence, when compared to the Original alternative, resulting in an EIR of 4.68; this ratio is almost twice as high as the Original alternative. The uneven energy matching increases empower from 24 to 34E21 seJ/yr, but emergy is less efficiently used. Within a short-term this alternative can prevail over all the other ones assessed here due to its economic power. However, in a scenario with lower oil availability, it could break down and cause higher damages (economic and social), when compared to the Original alternative.

(c) Regional matching alternative: Different from high developed regions (i.e., regions with high “F” dependence), the studied southern region of Minas Gerais state demands larger amounts of “I” than “F” resources; such characteristic results in a regional EIR lower than 1. When using this regional EIR as a parameter to match the milk production EIR, the resulting “F” inflow becomes lower than the “I” inflow and creates a scenario containing a limiting factor, in which “I” resources inflow are limited by “F”. This alternative is considered as unbalanced, resulting in an inefficient use of emergy. Its sustainability can be considered as higher than the previous two alternatives due to its lower “F” dependence as compared to “I”, but its empower is lower as well and cannot compete with alternatives systems at short-term period.
(d) Emergy matching alternative: as far as the efficient use of emergy and sustainability are concerned, this scenario could be considered as the best alternative of all. The balance between “F” and “I” inflows results in an existence of limiting factors in the milk production sector, thus emergy is used efficiently to maximize production. Additionally, this alternative reached a moderate empower, at the same time demanding a reduced amount of “F” resources when compared to the Regional Matching alternative, which guarantees higher power in the market competition at a higher sustainability degree.

Under a more holistic pattern of development, assuming that economic development is empower-dependent, and for the time-and-space window of regional economic development, the “Minas Leite” alternative should not be supported by governmental politics. Despite featuring higher empower for milk production (which means high economic power in short-term), the “Minas Leite” alternative for development can result in a lower efficiency of emergy use, and simultaneously, under unsustainable
bases. The best alternative for milk production in the region is when “F” resources match “I” ones, as shown in Figure 5d.

For a practical perspective, the Emergy Matching Alternative – the most appropriate one among the four ones assessed – means that the current milk production development in the southern region of Minas Gerais State should reduce its dependence on “F” resources from 17.40 to 6.76 E21 seJ/yr. Is this achievable? How to provide technical alternatives and economical incentives for producers aiming a sharp reduction on “F” resources dependence? Is there a way to combine the representativeness of current milk production systems (5% of G1, 32% of G2, 60% of G3, 2% of G4, and 1% of G5) in such a way that the overall “F” dependence is reduced? All these important aspects are not discussed in this present paper, but they are being taken into consideration for the next work regarding the management of regional milk production.

CONCLUSION

Considering the approaches and assumptions made in this work, the following conclusions were reached:

(a) Taking into account all the five groups identified for milk production in the southern region of Minas Gerais state, the G3 group can be considered as the most sustainable. It has 24% of renewability, contributes 2.03 seJ to the economy for every seJ invested, depends equally on both economical and natural resources (EIR of 0.97), and causes moderate environmental load (ELR of 3.06). Although showing low sustainability index (ESI of 0.66), its performance is higher than that of all other groups. On the other hand, its emergy efficiency is the lowest of all, with 1.68E+13 seJ/L milk;

(b) The “Minas Leite” governmental program which is intended to replace the G3 group by the G2 should not be considered as the best option under a holistic development pattern. Instead, the emergy matching alternative rises as a better choice by which the overall dependence of regional milk production on “F” emergy resources should be reduced from 17.40 to 6.76 E21 seJ/yr so as to reach higher sustainability.

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APPENDIX. Calculation procedure for the aggregated emergy flows of Southern Region of Minas Gerais State

Renewables (R)

Only the highest one is considered, so as to avoid double accounting

(i) Sun: solar radiation = 16 MJ/m²/day; Albedo = 20%; Emergy flow = 16MJ/m²/day * 365 days/yr * (1-0.2) * 10,000 m²/ha * 3,687,884 ha * 1 seJ/J = 1.72E20 seJ/yr

(ii) Rain: rainfall = 1.6 m³/m²/yr; Gibbs free energy = 5,000 J/kg; Emergy flow = 1.6 m³/m²/yr * 5,000 J/kg * 1,000 kg/m³ * 10,000 m²/ha * 3,687,884 ha * 3.10E4 seJ/J = 9.15E21 seJ/yr

(iii) Wind: Air density = 1.3 kg/m³; Average wind velocity = 4.7 m/s; Geotropic wind = 2.82 m/s; Drag coefficient = 0.001; Emergy flow = 1.3 kg/m³ * (2.82 m/s)³ * 0.001 * 10,000 m²/ha * 31.56E6 s/yr * 3,687,884 ha * 2.45E3 seJ/J = 8.30E19 seJ/yr

Nonrenewables (N)

Mineral extraction was disregarded because it is exported without use and contributes exclusively to GDP, not to total emergy; Soil loss (agricultural and natural areas) estimations based on official reports and personal communication with experts in the field = 6.45 ton/ha/yr; Emergy flow = 6.45 ton/ha/yr * 1.000 kg/ton * 0.04 kg of organic matter (o.m.)/kg * 5,400 kcal/kg(o.m.) * 4,186 J/kcal * 3,687,884 ha * 7.38E4 seJ/J = 1.59E21 seJ/yr

Feedback from economy (F)

Regional GDP = 16,067 million USD/yr; Region’s area = 14,239 miles²; Income density = 1.13 million USD/miles²/yr; Estimated “F” from Odum’s monogram (Odum, 1996 p. 76) = 0.11 million USD/miles²/yr; Emergy flow = 0.11E6 USD/miles²/yr * 3.40E12 seJ/USD * 1/259 miles²/ha * 3,687,884 ha = 5.31E21 seJ/yr