

Energy Scandinavia 2020

– Environmental Accounting

Proceedings from the 2nd
Scandinavian Energy Symposium,
21 February, 2020,
Mid Sweden University,
Östersund, Sweden

Erik Grönlund (red./ed.)

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Mid Sweden University
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Table of contents

Förord	iv
Preface	vi
Program	ix
Deltagare / Participants	xi
Welcome to Emergy Scandinavia 2020.....	xiii
Emergialgebra. <i>Torbjörn Rydberg</i>	1
Miljöräkenskaper och Emergi. <i>Torbjörn Rydberg</i>	13
Emergiperspektiv på hållbar stadsutveckling. <i>Daniel Bergquist</i>	17
An analysis of the Energy-related concepts Energy, Exergy and Embodied Energy and in what way they reflect environmental load. <i>Torbjörn Skytt</i>	21
Energy and water – findings from Cyprus' and Sweden's water balances. <i>Elena Paschali and Erik Grönlund</i>	27
Energy – providing the basis for a more equal world? <i>Anja Eliasson</i>	31
Energy view on sustainability compared to environmental science textbooks' views on sustainability <i>Erik Grönlund</i>	35
Energy on different scales: the case study Norderön – Jämtland – Sweden. <i>Daniel Hedin and Erik Grönlund</i>	53
Oväntat olika värden på energi jämfört med energi från månen och jordens inre. <i>Erik Grönlund</i>	57
Emergipublicationer med anknytning till Skandinavien 1994-2019. <i>Erik Grönlund</i>	59

Förord

Varför behövs ett symposium om emergi i Skandinavien? Ett svar är naturligtvis rent kunskapsorienterat. Emergi är ett av de nya vetenskapliga begrepp som lyckas med att inkludera mer av kvalitativa aspekter hos system, vilket saknats i många tidigare tillgängliga kvantitativa beskrivningar av verkligheten. Emergi beskriver verkligheten på ett nytt sätt som verkar ligga närmare det många av oss upplever. Ett annat svar är att ett symposium katalyserar projekt kring ämnet. Väl värt att påminna om syftet i förra årets stora emergi-ansökan till VINNOVA¹: "...att accelerera regioners klimatstrategiska arbete genom ett effektivare beslutsstöd baserat på emergianalyser. Kvantitativa systemanalyser för större skalnivåer – städer, regioner, länder – är idag en bristvara för beslutsfattare. Emergianalyser kan bidra till att fylla denna lucka, och är nu redo att ta steget från ett vetenskapligt analysverktyg inom universitetsvärlden till att bli ett beslutsstöd för att uppnå mål i regioners klimatstrategier."

Sverige, med AnnMari och Bengt-Owe Jansson i spetsen, var tidigt med i utvecklingen av emergi-begreppet under 1970- och 1980-talet. Under milleniets första decennium var SLU Ultuna ett nav för emergiforskning i Skandinavien. I Danmark har emergiforskning bedrivits vid Danmarks Tekniske Universitet, Institut for Kemiteknik. Idag har aktivitetsnivån kring emergi tyvärr gått ned i Skandinavien, medan den ökat i framförallt Italien och Kina. Ett syfte med en serie symposier kring emergi är att sammanfatta och utvärdera vad som gjorts hittills, och vilken relevans det kan ha för kommande forskning och användning i samhället i skandinavisk kontext. Mycket av det som har publicerats finns bara tillgängligt på engelska i den (ofta alltför) komprimerade kommunikationsform som används i internationella vetenskapliga tidskrifter.

En fråga som lyftes i årets symposium var om vi ska vara mer tematiska kommande år. Förra året hade symposiet underrubriken "Assessing both Nature and Society", och i år "Environmental Accounting". Årets diskussion utmynnade i att flera var intresserade av multifunktionalitet som tema, liksom hur vi mäter effektivitet (efficiency). Så här kanske kommande symposiers fokus kunna se ut (även om det naturligtvis alltid också speglar vad som gjorts under året och vad som är på modet just nu):

- Energy Scandinavia 20XX: Multifunctionality and efficiency
- Energy Scandinavia 20XX: A complement to LCA?
 - o Meaning focus on the relations to other methods, formulated a little provocative.
- Energy Scandinavia 20XX: Assessing regions and nations
 - o There is a long series of nation level energy analyses for Sweden, and Denmark. Norway is also included in the new updated NEAD database (<http://www.energy-nead.com>). How solid are they, and what conclusions can be drawn?

¹ Ansökan till VINNOVA (Verket för innovationssystem) gjordes i samarbete mellan Mittuniversitetet, SLU Ultuna, samt Regionerna i Jämtland-Härjedalen och Uppsala. Även Västmanland var intresserade, men hann inte komma med innan deadline. Tyvärr fick ansökan avslag, även om det var med goda vitsord.

- Energy Scandinavia 20XX: Sustainable Agriculture
 - o The field where most Swedish and Danish investigations had their focus.
- Energy Scandinavia 20XX: Sustainable Forestry
 - o Several investigations from Sweden exists. How to interpret them?

Listan kan göra mycket längre.

Slutligen kan det vara relevant att upprepa förra årets resonemang kring val av språk och ord som Symposium och Proceedings:

- Vad skulle mötet kallas? "Konferens" är det vanligaste ordet som brukar användas, men brukar samlas större skaror än detta möte gjorde. Vi är relativt få som idag är aktiva inom emergifältet. Jag uppskattar att runt 75% av oss som är eller har varit ledande inom området i Skandinavien deltog i mötet. Så "konferens" kunde vara relevant ur den aspekten. Efter en del letande dök det kanske lite gammelklingande ordet "Symposium" upp, och visade sig betyda just "liten konferens", så det fick det bli!
- Vad skulle dokumentationen från symposiet kallas? "Proceedings" är det engelska ordet som brukar användas. Det verkar inte finnas något riktigt modernt etablerat svenska ord. Proceedings översätts med "förfaranden" eller "protokoll" eller möjligtvis "förhandlingar" enligt Google translate. "Notater" kunde vara en annan möjlighet, eller helt enkelt "Dokumentation". Ingen av dessa översättningar klingar särskilt uppdaterat. Proceedings är det ord som används i vetenskapliga kretsar, så det fick bli namnet även på detta.
- Vilket språk? Å ena sidan var ett av syftena med symposiet att göra tillgängligt innehåll om energi på svenska, danska och norska. Å andra sidan är universitet idag oftast internationella miljöer. Det är nästan alltid någon besökande gästforskare eller internationella studenter som en inte vill stänga ute. Och så var fallet även här. Eftersom några av symposie-deltagarna inte pratade svenska blev det naturligt att språket blev engelska. I denna Proceedings är dock de flesta bidrag på svenska. Nu blev det "bara" svenska och engelska. Vi hoppas på danska och eventuellt norska bidrag till kommande proceedings. Ingen från närområdet, Finland och de baltiska staterna, denna gång, men kanske på kommande symposier?

Till sist ett tack till Institutionen för Ekoteknik och hållbart byggande vid Mittuniversitet, som stått för omkostnader och varit värd för symposiet.

Östersund, 15 december 2020,

Erik Grönlund, koordinator för symposiet.

Preface

Why is there a need for a symposium on emergy in Scandinavia? One possible answer is, of course, purely knowledge-oriented. Emergy is one of the new concepts that manages to include more of qualitative aspects of systems that was often lacking in previously available quantitative descriptions of reality. Emergy describes reality in a new way that seems to be closer to what many of us experience. Another answer is that a symposium catalyzes projects around the subject. Actually, last year's symposium became the starting point for a larger application that was eventually addressed to one of the larger governmental funding agencies, VINNOVA. It is well worth recalling the purpose described in the application: "... to accelerate regions' climate strategic work through more effective decision support, based on emerging analyzes. Quantitative system analyzes for larger scale levels - cities, regions, countries - are today in short supply for decision-makers. Emergy analyzes can help fill this gap, and are now ready to take the step from a scientific analysis tool within the university world to becoming a decision support tool to achieve goals in regions' climate strategies."

Sweden, with AnnMari and Bengt-Owe Jansson at the forefront, was participating early in the development of the emergy concept in the 1970s and 1980s. During the first decade of the millennium, SLU Ultuna was a hub for emergy research in Scandinavia. In Denmark, emergy research has been conducted at the Technical University of Denmark, Department of Chemical Engineering. Today, the level of activity around emergy has unfortunately declined in Scandinavia, while it has increased mainly in Italy and China. One purpose of a series of symposium on emergy is to summarize and evaluate what has been done so far, and what relevance it may have for future research and use in society in Scandinavia. Much of what has been published is available only in English and the (often too) compacted form of communication used in international scientific journals.

One question that was raised in this year's symposium was whether we should be more thematic in the coming years. Last year, the symposium was subtitled "Assessing both Nature and Society", and this year "Environmental Accounting". This year's discussion resulted in several people being interested in multifunctionality as a theme, as well as how we measure efficiency. This is perhaps what the focus of future symposia might look like (although of course it always reflects what has been done during the year and what is popular right now):

- Emergy Scandinavia 20XX: Multifunctionality and efficiency
- Emergy Scandinavia 20XX: A complement to LCA?
 - o Meaning focus on the relations to other methods, formulated a little provocative.
- Emergy Scandinavia 20XX: Assessing regions and nations
 - o There is a long series of nation level emergy analyses for Sweden, and Denmark. Norway is also included in the new updated NEAD database (<http://www.emergy-nead.com>). How solid are they, and what conclusions can be drawn?

- Energy Scandinavia 20XX: Sustainable Agriculture
 - o The field where most Swedish and Danish investigations had their focus.
- Energy Scandinavia 20XX: Sustainable Forestry
 - o Several investigations from Sweden exists. How to interpret them?

The list can be made much longer.

Finally, I want to thank the Department of Ecotechnology and Sustainable Building Engineering at Mid Sweden University, who took care of the costs and hosted the symposium.

Östersund, 15 december 2020,

Erik Grönlund, coordinator for the symposium.

Program

09:00 Welcome to Emergy Scandinavia 2020. *Erik Grönlund*
09:05 Short presentation round of participants.
09:20 Emergy basics: the energy hierarchy, and maximum empower – suggested 4th and 5th laws of Thermodynamics. *Torbjörn Rydberg*
10:20 Paus.
10:40 Emergy synthesis of a "green" Urban District in Uppsala, Sweden. *Daniel Bergquist, SLU*
11:10 Emergy and money – real wealth. *Torbjörn Rydberg*
11:35 An analysis of the Energy-related concepts Emergy, Exergy and Embodied Energy and in what way they reflect environmental load. *Torbjörn Skytt*
12-13 Lunch.
13:00 Emergy – providing the basis for a more equal world? *Anja Eliasson*
13:15 Environmental accounting. *Erik Grönlund*
13:35 Emergy view on sustainability compared to some environmental science textbook views on sustainability. *Erik Grönlund.*
14:00 Paus
14:10 Presentation of two Master by Research positions at Mid Sweden University. *Erik Grönlund*
14:15 Summary discussion: questions emerging from previous presentations, and strategies for future energy research, symposia themes for coming years. *Torbjörn Rydberg, Erik Grönlund*
14:55 Final remarks.
15:00 End

Posters från symposiet / Posters from the symposium:

- Emergy – providing the basis for a more equal world? *Anja Eliasson*
- Emergy and water – findings from Cyprus' and Sweden's water balances. *Elena Paschali and Erik Grönlund*
- Emergi-algebra.
- Emergy on different scales – case study Norderön - Jämtland – Sweden. *Daniel Hedin and Erik Grönlund*
- Emergipublicationer med anknytning till Skandinavien 1994-2019. *Erik Grönlund*
- Oväntat olika värden på energi jämfört med emergi från månen och jordens inre. *Erik Grönlund*
- Systems ecology–Jørgensen vs. Odum. *Erik Grönlund*

Deltagare / Participants

Daniel Bergquist, SLU

Isabelle Boltzius, Mid Sweden University

Chris Celis, Mid Sweden University

Itai Danielski, Mid Sweden University

Anja Eliasson, Mid Sweden University

Erik Grönlund, Mid Sweden University

Henrik Haller, Mid Sweden University

Daniel Hedin

Åsa Lind Chong, Mid Sweden University

Volker Mauerhofer, Mid Sweden University

Elena Paschali, Mid Sweden University

Sepideh Razavi, Mid Sweden University

Torbjörn Rydberg

Torbjörn Skytt, Mid Sweden University

Anna Stugvard

Welcome to Energy Scandinavia 2020

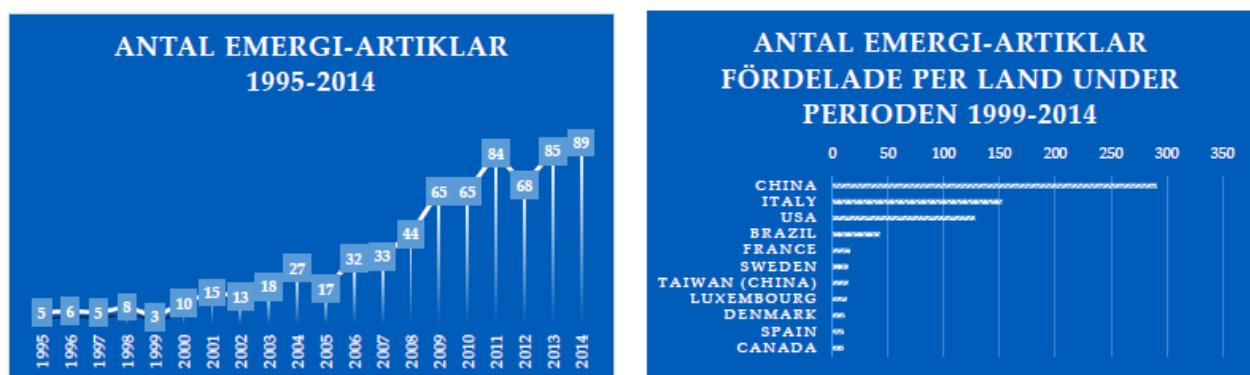
Energy and emergy analysis/synthesis is a concept and method with high potential as a system analytical tool as useful as LCA, energy systems analysis, exergy analysis, ecological footprints, and similar methods.

Still, emergy has not yet become a widespread method in Sweden. With purpose to see if emergy can find more applications and increased use in Sweden and Scandinavia, a yearly symposium is launched with focus on use of the emergy concept and method.

There are a lot of data regarding Sweden that is interesting to reconsider:

- The Gotland study
- Several thesis' from 1999 up to now.
- Some Master thesis' material.
- Florida proceedings material from 2001 up to now.
- The new NEAD database (energy-nead.com)

Below are two diagrams (Grönlund, 2017) where we can see the number of emergy papers published each year in scientific journals from 1995-2014. From approximately five per year during the 1990s it has increased to approximately 80-90 during the 2010s. We can also see that Sweden is number 6 and Denmark number 9 regarding number of published papers. (it was pointed out at the symposium that maybe Australia is missing in the statistics).

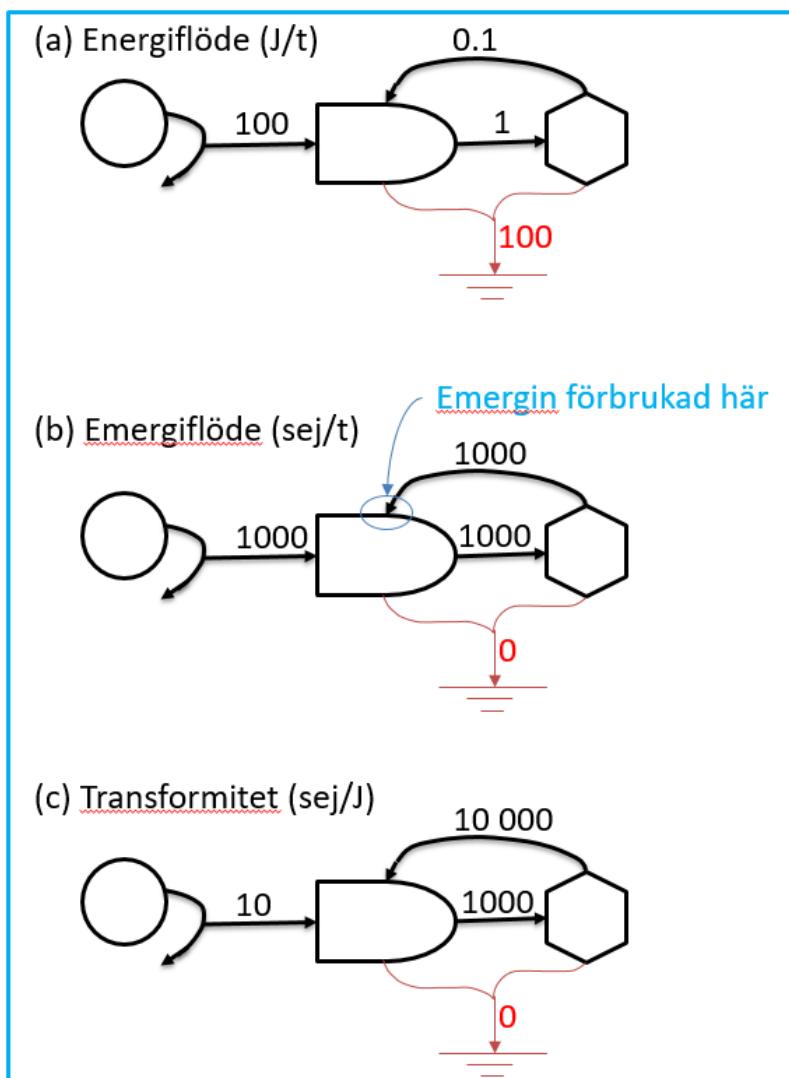


Erik Grönlund, coordinator of the Symposium

Emergialgebra

Torbjörn Rydberg

En metod som utger sig för att vara både kvalitativ och kvantitativ behöver naturligtvis regler för hur beräkningar utföres. Här nedan (fig. 1-9) visas viktiga räknereglerna i emergi-algebra (huvud-saklingen från Odum, 1996).



Figur 1. Grundprincipen för emergiberäkningar i ett exempel med 1 källa (cirkel), 1 producent ("bullet") och 1 konsument (hexagon).

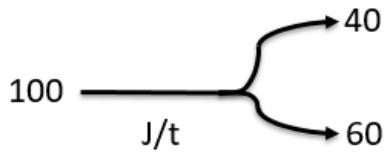
(a) visar ett energiflöde till konsumenten på $100 \text{ J per tidsenhet och yta}$. Vidare till konsumentledet går 1% , dvs. 1 J . Allt omvandlas till värme: $100 \text{ J nedåt till "heat sink", värmeförluster}$. Det finns en återkoppling från konsument till producent på $0,1 \text{ J}$, vilket skulle kunna vara återföring av näring, samt informationsinnehållet i hur den näringen distribueras.

(b) visar emergiflödet i samma system. Eftersom emergi är ett mått på hur mycket energi som krävs för att upprätthålla hela systemet, får alla flöden värdet 1000 seis , utom värmeförlusten, som får värdet 0 . Här ser vi "tumregeln" som används för när en slutar addera emergi från

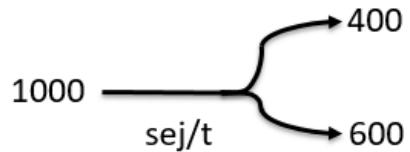
olika källor. Tumregeln lyder: när kedjan korsar sin egen svans, kan inte emergi adderas. De 1000 seis som kommer från källan, är de enda 1000 seis som är nödvändiga för det producenten transformerat likväld för det som konsumenten transformerat. Konsumentens återkoppling, har också genererats av detta emergiflöde, men kan inte adderas till systemet då det återkopplar. Detta skulle i så fall innebära en dubbelräkning av emergi.

(c) Visar hur transformiteten beräknas: emergiflödet delat med energiflödet.

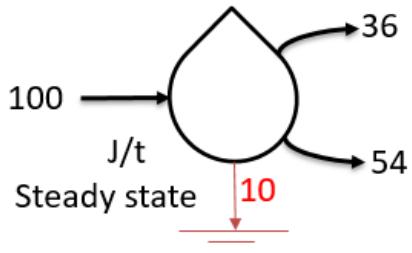
(a) Split av energiflöde av en sort



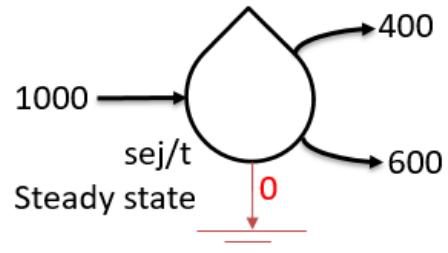
Emergiflödes-split



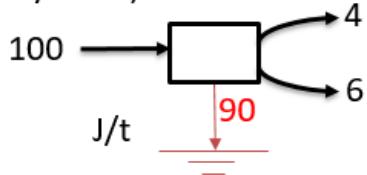
(b) Utflöde av energi av en sort



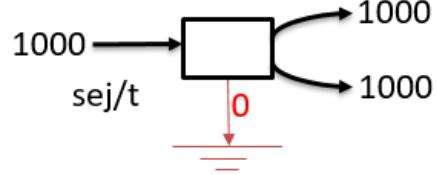
Emergiflödes-split



(c) Energiflöde där energin konserveras genom en tvåarmad energi-omvandling (steady state)



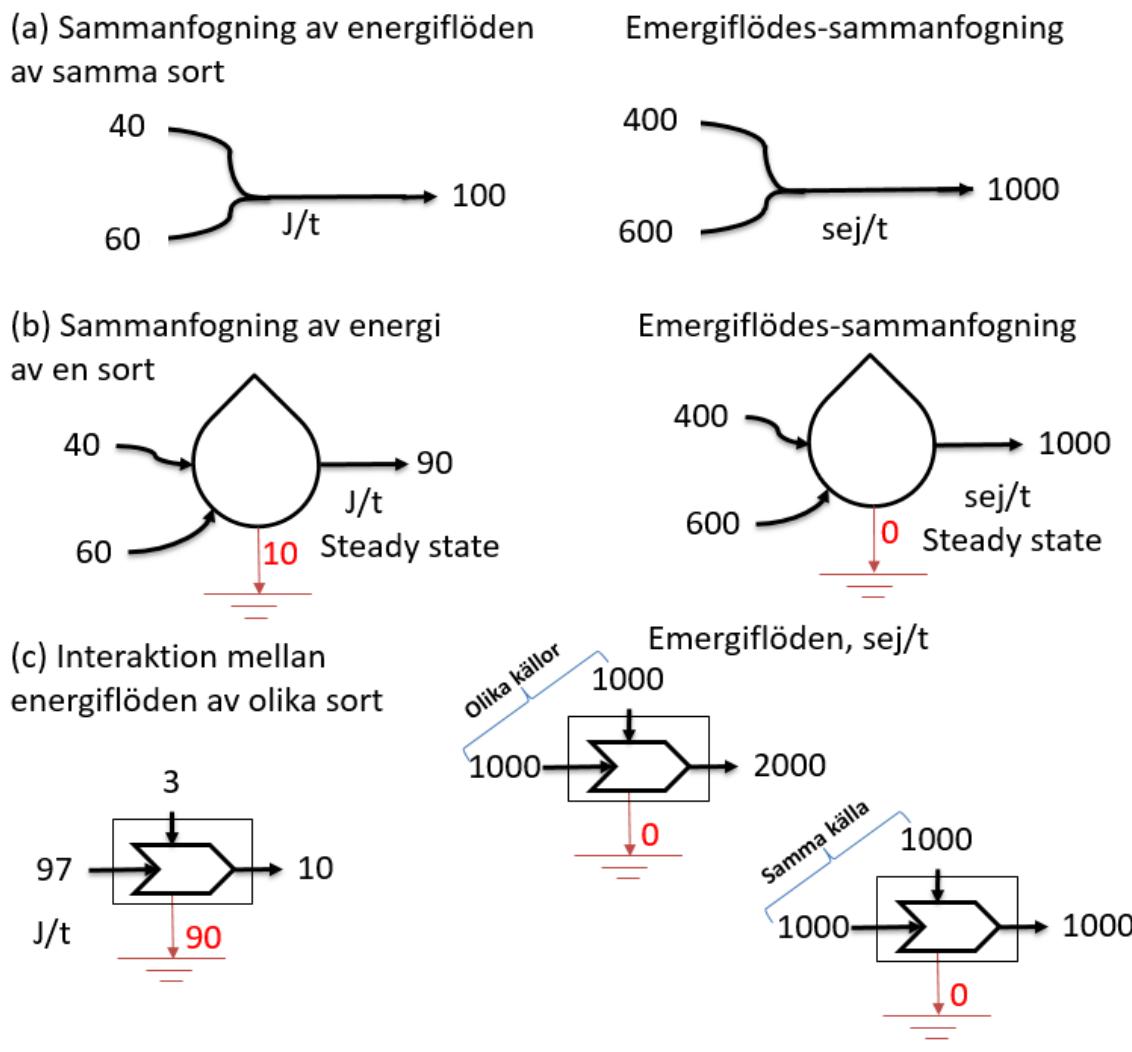
Biproduct-grenar som båda bär samma emergiflöde



Figur 2. Emergiflöden genom förgreningar. (a) Till vänster ett energiflöde som delar upp sig i två grenar. Skulle kunna vara en älvs som delar upp sig i två älvgrenar, eller ett vattendistributionssystem. I mitten emergiflödet som också delar upp sig i två delar eftersom inga energiomvandlingar skett. Denna typ av förgrening kallas "splits".

(b) En likadan uppdelning men med ett lager som fördöjer tiden. Skulle kunna vara ett vattentillförselsystem till en brunn som sedan tappas av åt två håll. Ännu en "split".

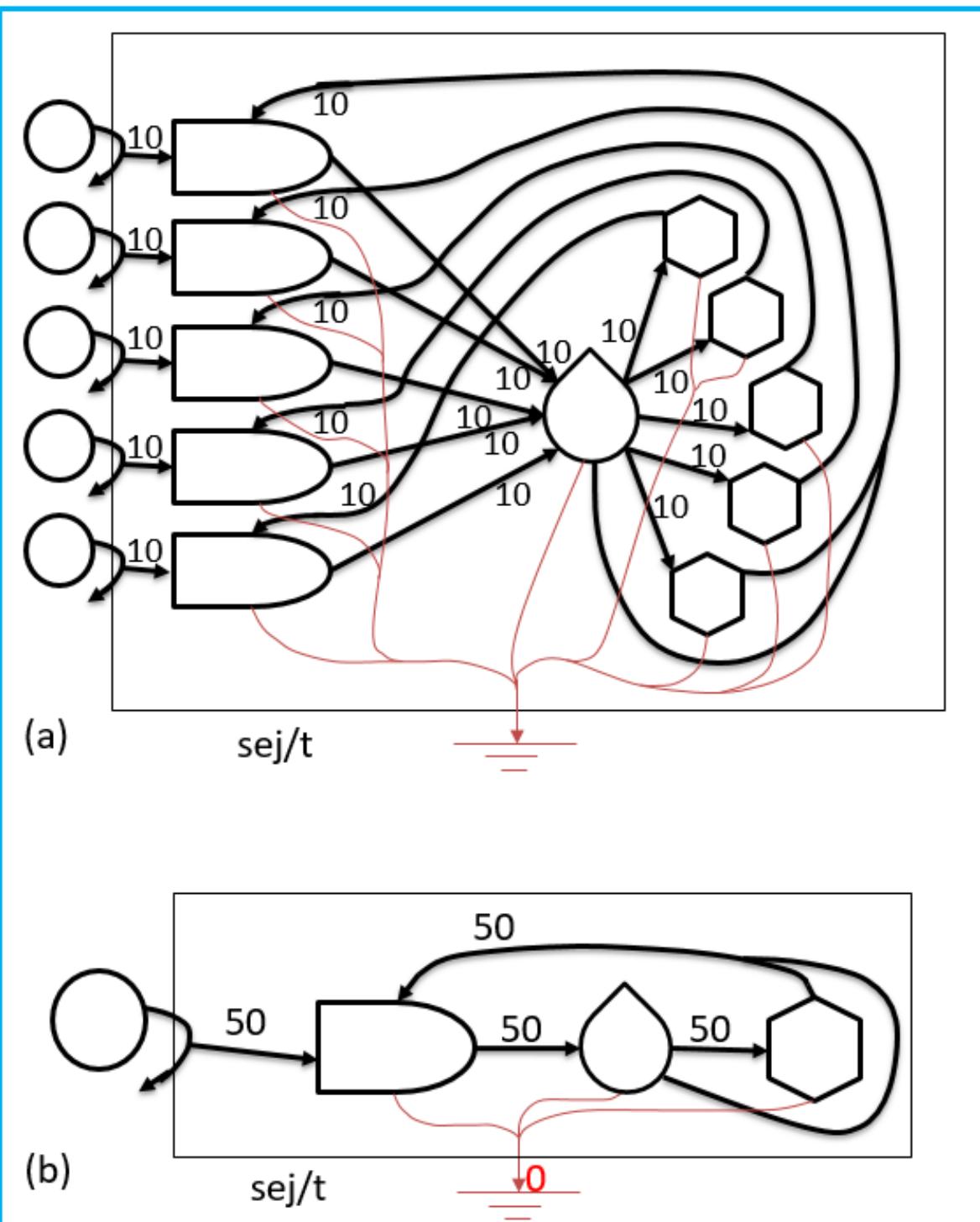
(c) En förgrening som innehåller en energi-omvandling. Det kan vara en ko som tillförs 100 J mat, och kan ge 6 J kött och 4 J kohud. 90 J går förlorad som värmeförlust. Här krävs 1000 sej för att skapa både köttet och skinnet. Inget av det kan skapas utan att hela kon finns. Därför följer hela emergen, 1000 sej, båda armarna. Denna typ av förgrening kallas "coproducts" (eller by-products).



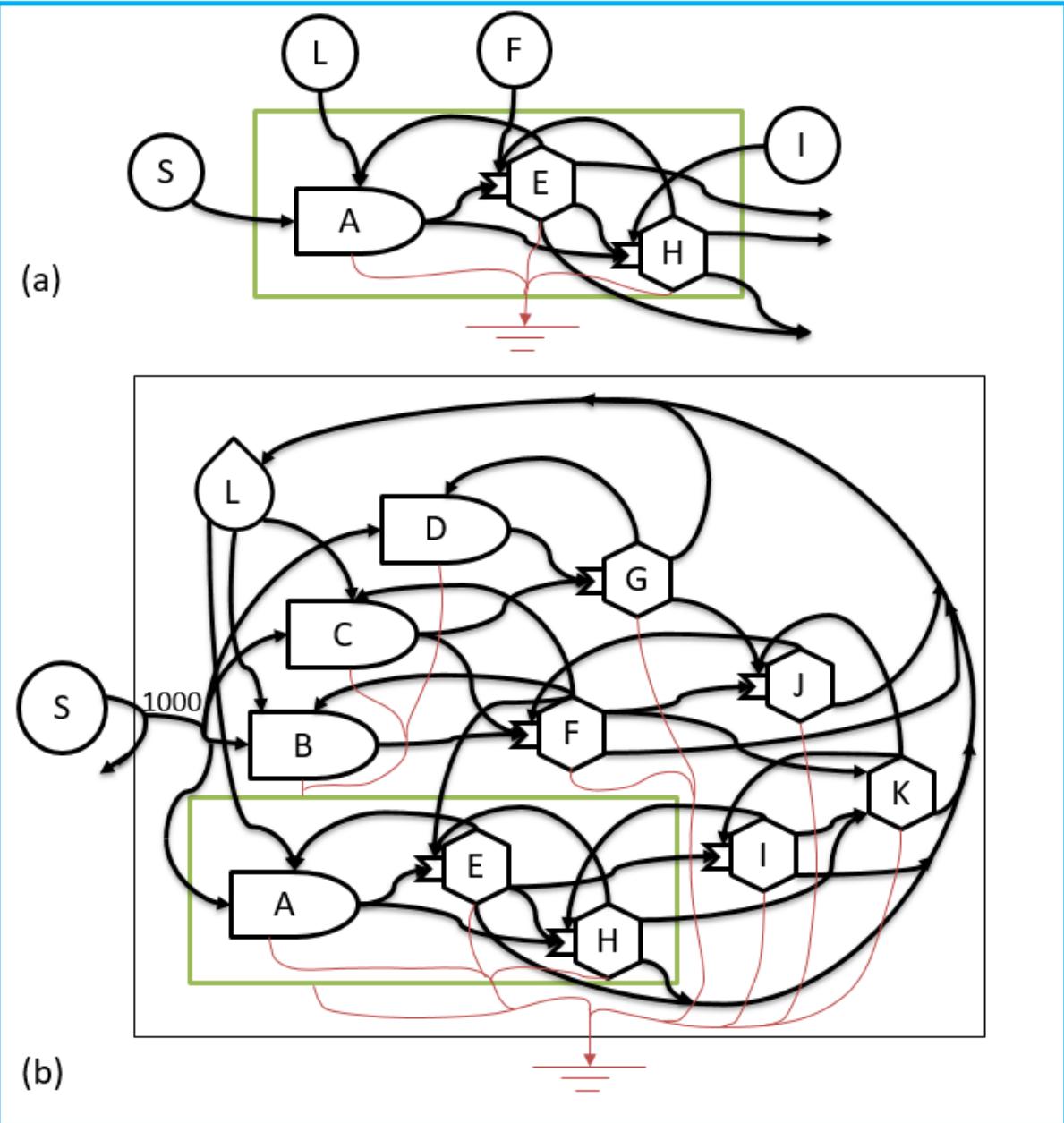
Figur 3. Emergieflöden genom intersektioner. (a) till vänster två energiflöden som löper ihop, utan att det sker någon energi-omvandling. Till höger emergin som adderas på motsvarande sätt som i fig. 2.

(b) En likadan sammanfogning med ett lager, motsvarande den i fig. 2.

(c) En interaktion sker, där båda inkommende grenarna behövs för att producera de två utgående grenarna. Energiomvandlingar har skett. Kan vara en kemisk reaktion eller en industri där två olika delar sätts ihop till en produkt. Emergiberäkningarna med separata källor eller samma källa förklaras i fig. 5.

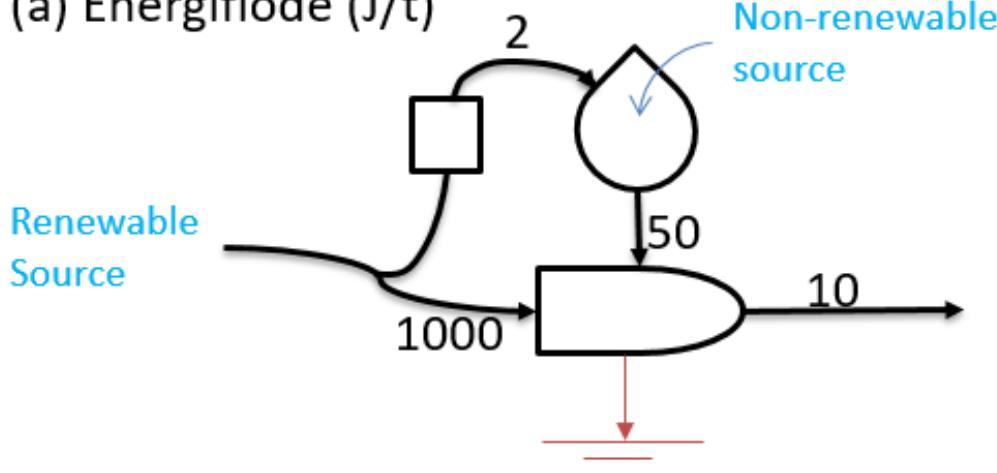


Figur 4. Aggregeringar. (a) representerar till exempel 5 bönder som levererar till ett gemensamt lager, varifrån varan levereras ut till 5 hushåll (splits). Hushållen levererar sedan restprodukter tillbaka till odlingen. (b) visar samma system men med aggrgerade emergiflöden.

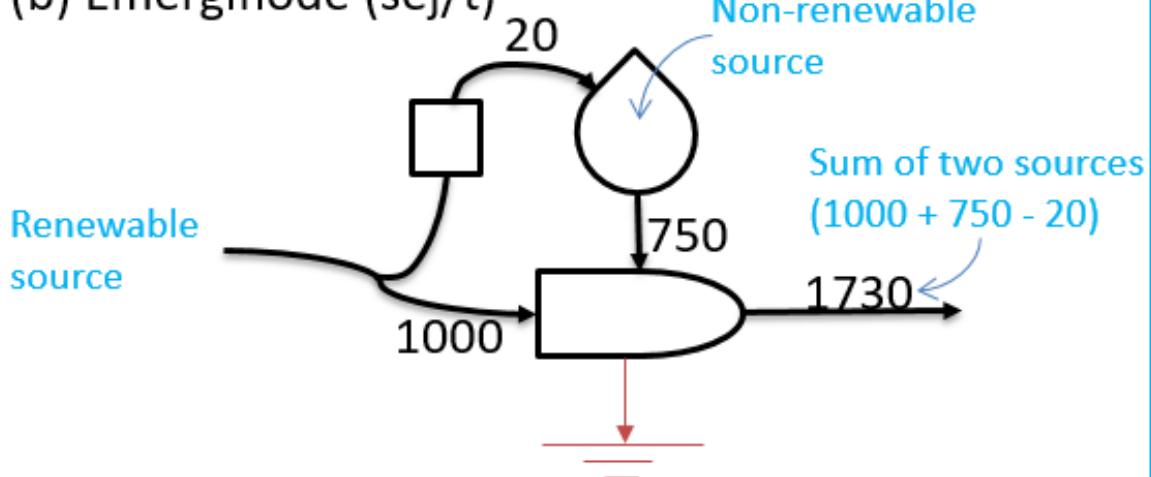


Figur 5. Oberoende eller beroende samband. (a) visar ett system med en produktionsenhet och två konsumerande enheter. Systemet drivs av fyra källor utanför systemet, vilka ser ut att vara oberoende. (b) visar ett större systemfönster som innesluter systemfönstret i a. Utvidgningen av systemfönstret visar att källorna L, F och I var beroende av varandra, och ytterst drivna av källan S. Emergin för hela systemet är 1000 sej, och att addera S, L, F och I skulle innehärra en felaktig dubbelräkning av energi..

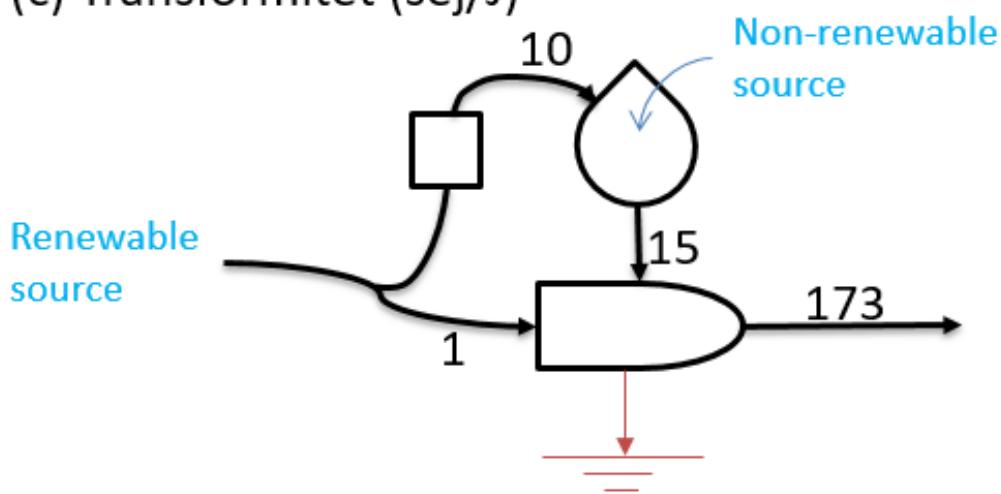
(a) Energiflöde (J/t)



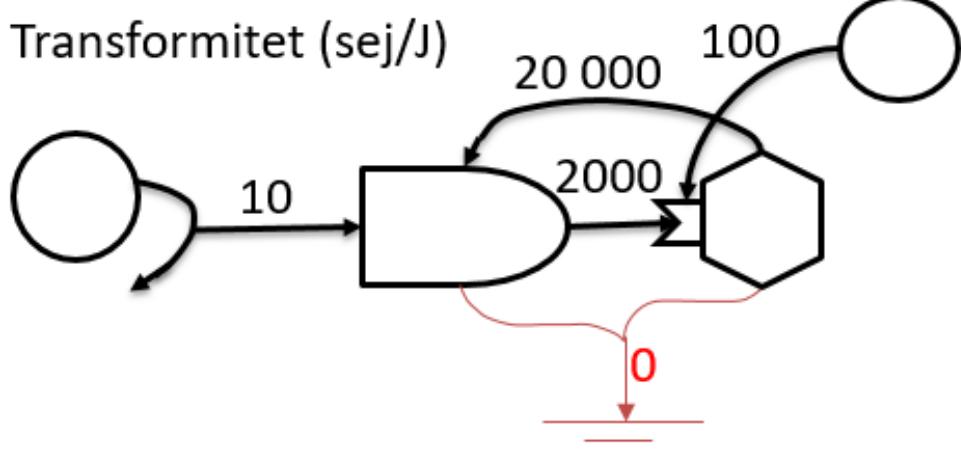
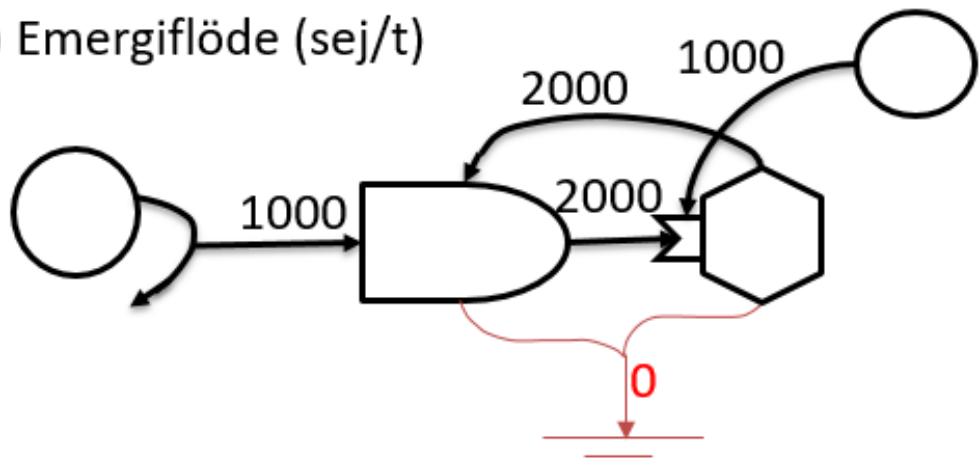
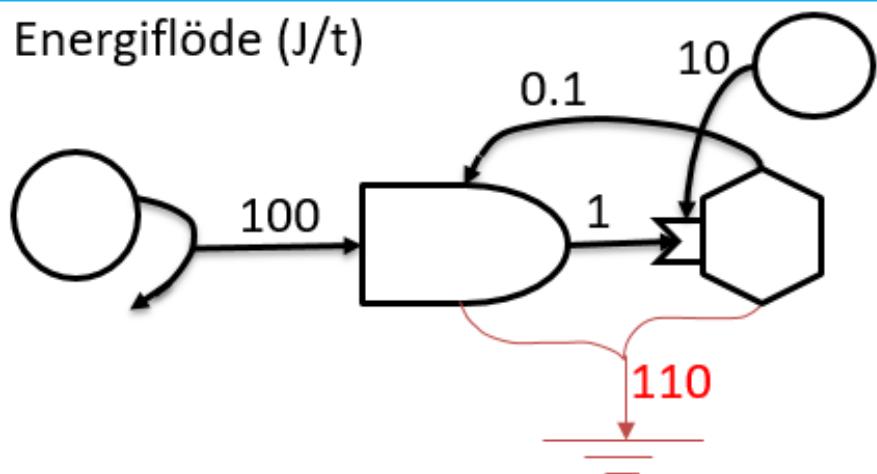
(b) Emergiflöde (sej/t)



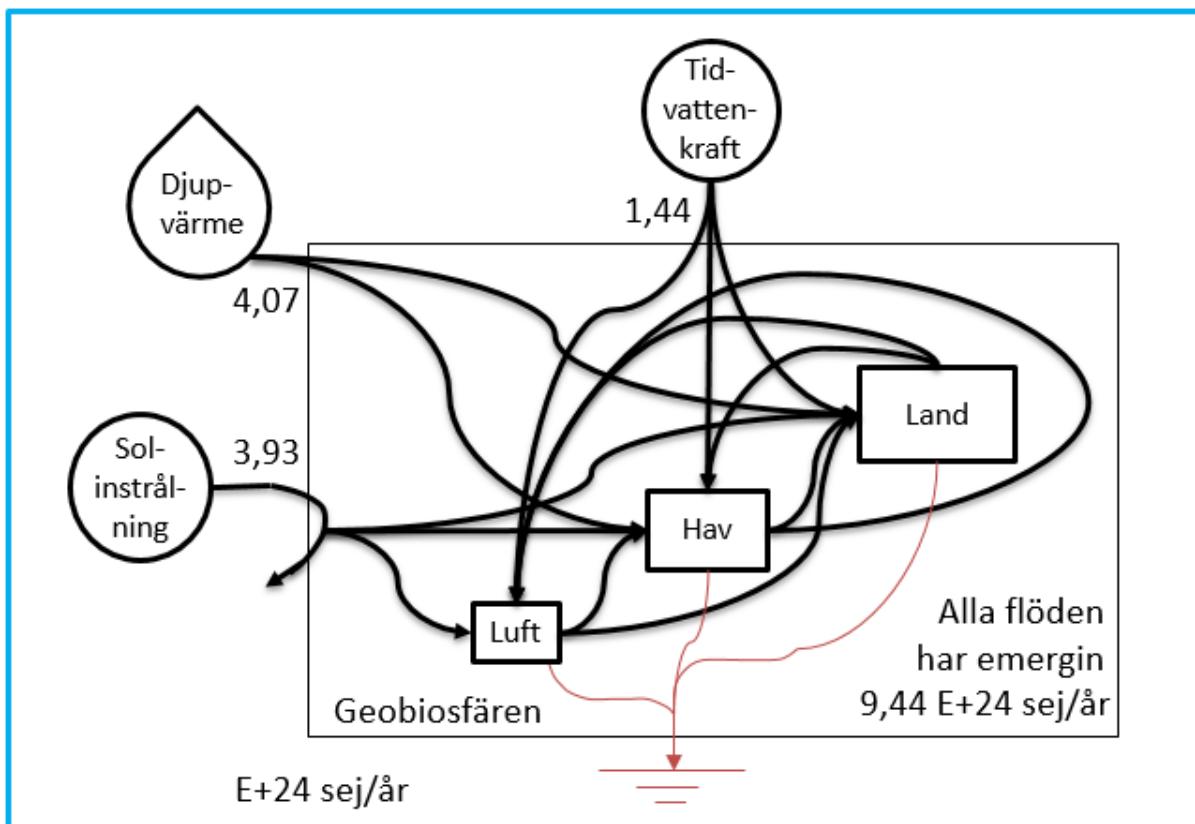
(c) Transformitet (sej/J)



Figur 6. Icke förnyelsebara lager. I figuren visas hur två förgreningar som kommer från samma källa, ändå kan adderas. Detta eftersom det finns en fördräjning i tiden för den övre grenen. Det innebär att när grenarna möts i produktionssymbolen kommer de in från olika tidsfönster i ursprungskällan. De är alltså oberoende i tid. I emergidiagrammet ser vi att den historiska (lagrade) tillförseln, 750 seul adderas till det nutida flödet, 1000 seul, samtidigt som den nutida tillförseln till lagret, 20 seul, dras av från 750 seul.

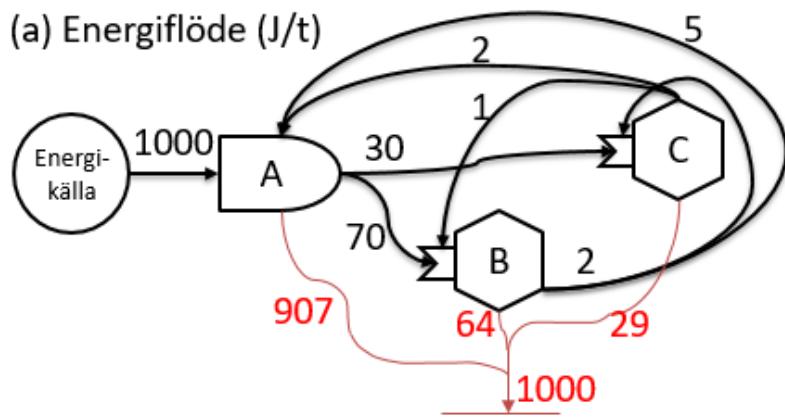


Figur 7. Två externa källor som är oberoende av varandra. Emergin adderas för varje källa för sig tills additionen korsar den "egna svansen".



Figur 8. Tre oberoende källor (Solar insolation, Deep Earth Heat, Tide), som interagerar som coproducts, vilket innebär att de adderas och hela systemet bär hela den summerade emergen, $9.44\text{E}+24$ sej/år.

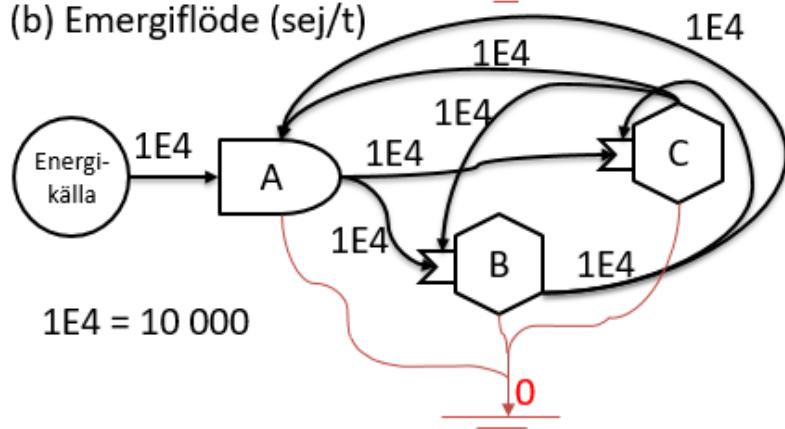
(a) Energiflöde (J/t)



		Till		
		A	B	C
Från	A	0	70	30
	B	5	0	2
	C	2	1	0

Inter-sektor energiflöden

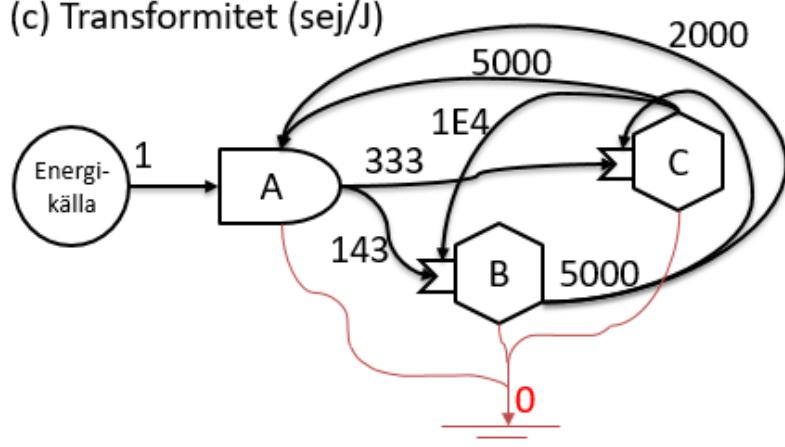
(b) Emergiflöde (sej/t)



		Till		
		A	B	C
Från	A	0	10^4	10^4
	B	10^4	0	10^4
	C	10^4	10^4	0

Inter-sektor emergiflöden

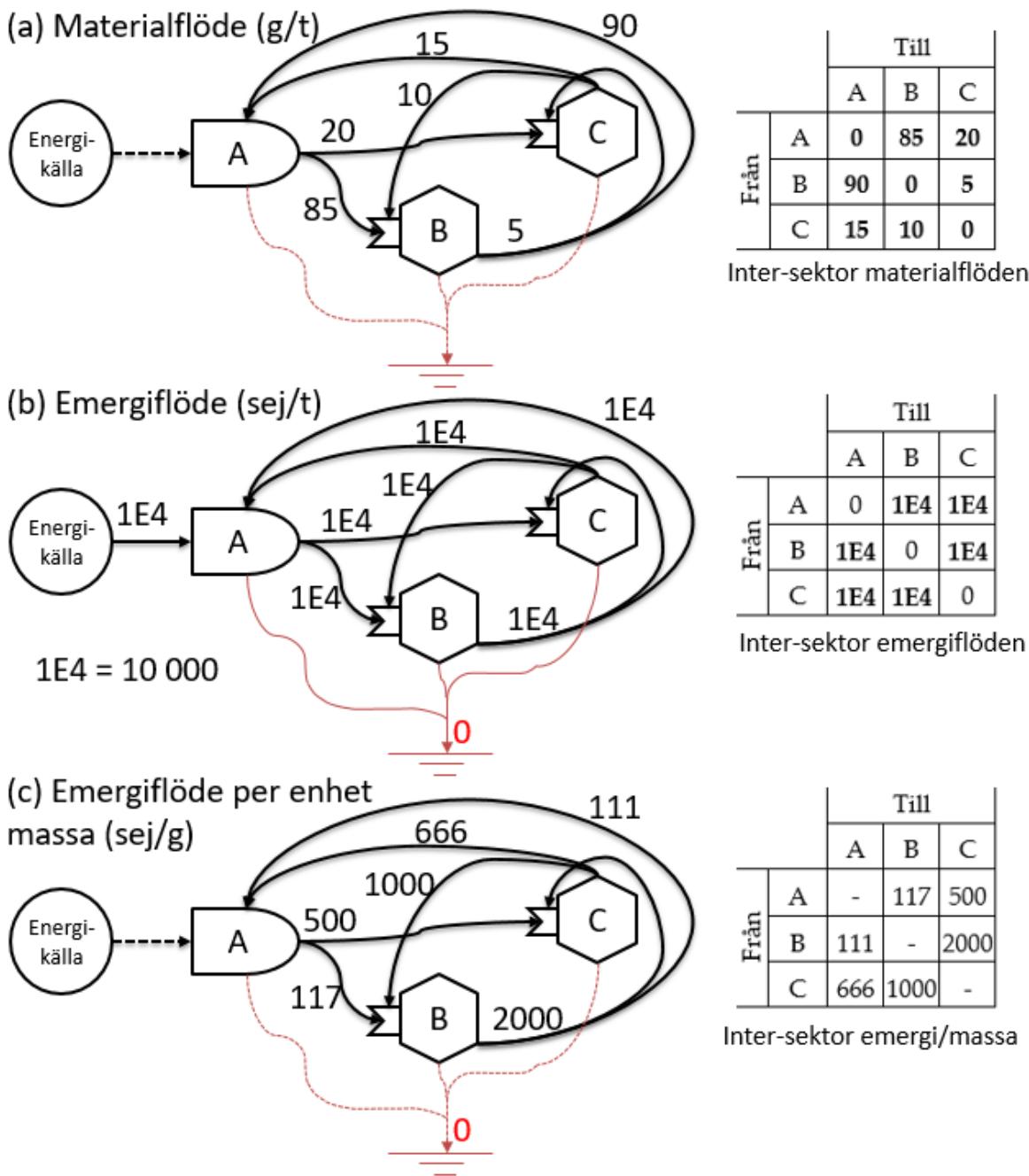
(c) Transformitet (sej/J)



		Till		
		A	B	C
Från	A	-	143	333
	B	2000	-	5000
	C	5000	10^4	-

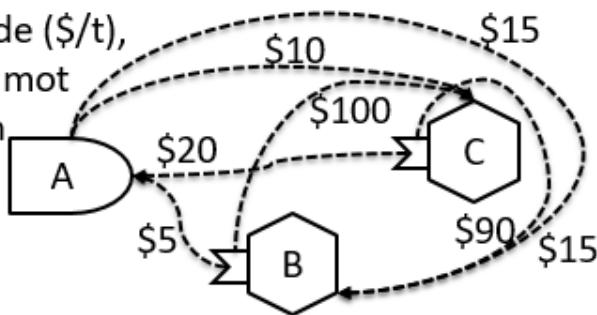
Inter-sektor transformiteter

Figur 9a. Spår-summering (Track-summing). I fig. 6, 7 och 8 beräknas emergin för varje spår för sig. Tennenbaum (1988) utvecklade en mer generell princip för summering (Track-summing). Här visas exempel på detta för energi (9a), material (9b), och pengar (9c).



Figur 9b. Spår-summering (Track-summing). I fig. 6, 7 och 8 beräknas emergin för varje spår för sig. Tennenbaum (1988) utvecklade en mer generell princip för summering (Track-summing). Här visas exempel på detta för energi (9a), material (9b), och pengar (9c).

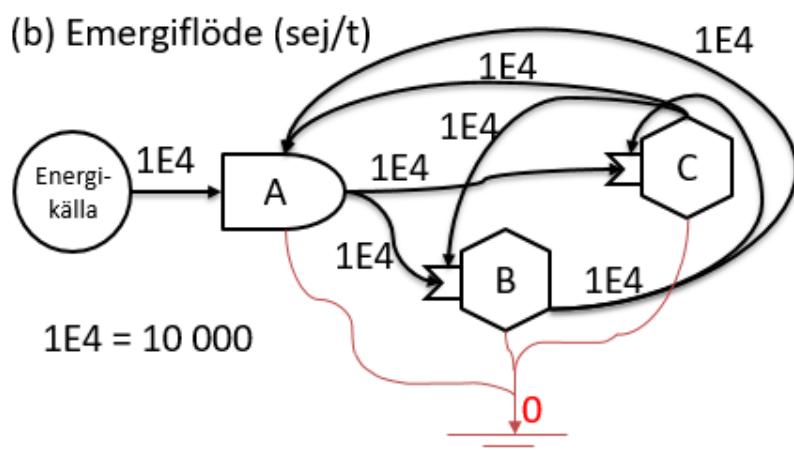
(a) Pengaflöde (\$/t),
motsatt håll mot
energiflöden



		Till		
		A	B	C
Från	A	0	5	20
	B	15	0	90
C		10	100	0

Inter-sektor pengaflöden

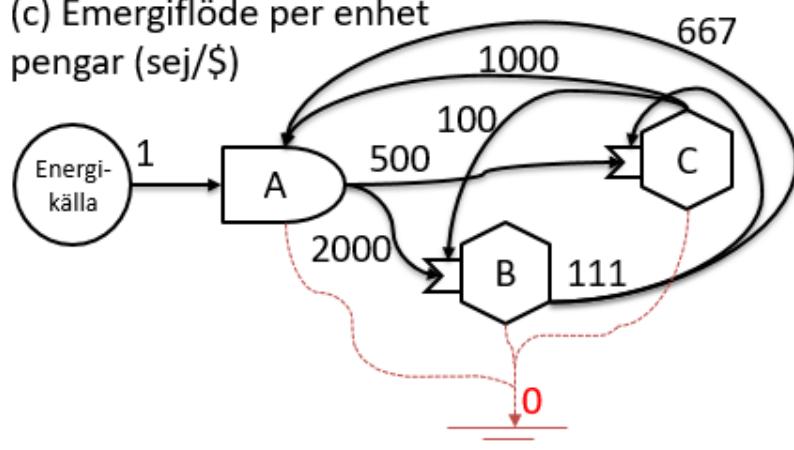
(b) Emergiflöde (sej/t)



		Till		
		A	B	C
Från	A	0	1E4	1E4
	B	1E4	0	1E4
C		1E4	1E4	0

Inter-sektor emergiflöden

(c) Emergiflöde per enhet
pengar (sej/\$)



		Till		
		A	B	C
Från	A	-	2000	500
	B	667	-	111
C		1000	100	-

Inter-sektor energi/pengar

Figur 9c. Spår-summering (Track-summing). I fig. 6, 7 och 8 beräknas emergin för varje spår för sig. Tennenbaum (1988) utvecklade en mer generell princip för summering (Track-summing). Här visas exempel på detta för energi (9a), material (9b), och pengar (9c).

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Miljöräkenskaper och Emergi

Torbjörn Rydberg

Ekosystemtjänster och miljöräkenskaper

Ekosystem har oftast blivit värderade utifrån deras förmåga att producera något som kan ses som värdefullt för människan och människans samhälle och samtidigt ges ett monetärt värde..

Till exempel:

- Strandängar kan ges ett monetärt värde som är beroende av en uppfattad vinst från fiskproduktion, turism och rekreation.
- Beskogade marker kan bli värderade på basen av deras säljbbara timmer.

Dessa typer av utvärderingar har sitt fokus på ekosystemens funktioner och lager som har ett marknadsvärde och därmed kan säljas som en vara i exemplen som fisk eller timmer.

Nu är det så att dessa typer av värderingar ignorerar andra icke-marknadsmässiga aspekter av ekosystemen, som till exempel deras förmåga att rena vatten och ge livsutrymme för flora och fauna. I litteraturen finns det flera tillvägagångssätt att värdera ekosystem. Tillvägagångssätten kan grupperas i två huvudkategorier.

1. ekonomisk värdering från uppskattade monetära vinster (mottagarbaserat värde),
2. energetisk värdering från ekosystemens processer och flödesvägar (givarbaserat värde)

Ekonomiska värderingar

Det finns flera typer av ekonomiska metoder att värdera naturkapital och ekosystemtjänster som saknar en tydlig monetär marknad (mer finns att läsa, till exempel (Björklund & Rydberg, 2003 ;SEEA, 2003)).:

- Betalningsvilja, bygger på mänskliga preferenser och upplevda vinster från ekosystemen. Med det som grund fastställs ett pris för icke-marknadsmässiga attribut.
- Markprisvärde. Metoden uppskattar ekosystemens värde utifrån den högsta ekonomiska användning som kan tänkas vara möjlig på den givna platsen.
- Substitutionsmetoder fastställer värden genom att beräkna hur mycket det skulle kosta att restaurera ekosystemet och dess naturkapital till sin ursprungliga status. Genom att addera kostnader för maskiner, produkter och monetär kostnad för arbete utförd a människor för restaureringsprocessen. Samtidigt ignoreras dessvärre alla andra värdefulla varor och tjänster av naturen.
- Alternativkostnad för bevarandet, kan i vissa fall skydda och bevara naturkapitalet så till vida att det man tänker sig genomföra inte har allt för stort ekonomiskt värde.

Alla dessa typer av ekonomiska värderingar har endast en relevans för att uppmärksamma naturresurser och ekosystemens tjänster om det finns en marknad för det. Till exempel fisk eller timmer. Vidare ger dessa metoder endast en subjektiv uppskattning av alla andra ekosystemtjänster som direkt och indirekt är beroende av, som till exempel infiltration, renin av luft, vatten lagring, förbättrad vattenkvalitet och värdet av vilda djur och växter.

Miljöräkenskaper som använder sig av termodynamisk beräkningsgrund

Howard T. Odum utvecklade en metod för värdering som var baserad på den totala mängden energi av en form som direkt och indirekt genom alla flödesvägar och tidigare processer behövdes för att göra

en vara eller tjänst (Odum, 1996). Konceptet kom att kallas emergi och populärt förklarat som ett slags "energiminne".

Den emergi som ackumuleras i ett system ökar med mognadsgraden och det beräknas genom multiplikation av energin som är i subjektet/objektet gånger dess specifika emergivärde (Unit Energy Value UEV).

UEVs, eller solemergi som behövs för att göra en joule eller gram av en service eller produkt kan beräknas genom att man dividerar produktens emergi genom dess energi eller massa. UEV ökar då processen blir mer raffinerad, och kan därför vara en mätare av mognad och effektivitet.

Till exempel, biomassan i en mer mogen skog, den äldre skogen kommer att ha ett högre värde på UEV än de yngre skogarna, eftersom dess emergi har haft längre tid på sig för ackumulering under en längre tid.

Emergi

Emergi kan ses som en mätare av verlig rikedom. Det är det arbete som måste ske för att generera en produkt eller tjänst. En vara eller tjänst som över tiden visat sig kunna förstärka hela systemet är värdefull i och med att den bidrar till hela systemets funktioner; hälsa, vitalitet, effektivitet, resiliens osv. I emergiteori så presenteras detta arbete på en gemensam bas, solemergi. Viktigt att förstå är att detta arbete innefattar så mycket mer än det rent fysiska mekaniska arbetet som definieras av mekanikens kraftlagar.

Arbetet som nödvändigtvis behövs för att generera en produkt eller tjänst, bildar då sedda i ett öppet systemperspektiv en energihierarki. I den uppstådda energihierarkin blir allt mindre energi tillgänglig vid varje progresiv nivå som ett resultat av att energin sprids i den tidigare arbetsprocessen. Till exempel, i hierarkin för biosfären så är det många joule sol som behövs för att generera en joule av organiskt material, många joule av organiskt material är grunden för att genererandet av en joule av formen drivmedel. Många joule av formen drivmedel åtgår för att generera exempelvis joule av formen el och så vidare.

Eftersom olika former av energi inte är lika till sin förmåga att verka i en process, arbete kan först göras jämförbart genom att man uttrycker varje form av energi i enheter av en annan form. I sin helhet, emergi genererar en djupare förståelse över hur systemen interagerar på varje skala tillsammans med annat framförallt i geobiosfären.

Emergi och emergiräkenskaper

Emergiträkenskap är ett givarbaserat kvalitetsbegrepp (Odum, 1996) som använder en vetenskaplig termodynamisk grund av alla former av energi och material, men omvandlar dem till ekvivalenter av en form av energi, vanligtvis solljus. Emergi är den mängd tillgänglig energi som krävs direkt och indirekt att göra något. Emergi blir då är ett mått på de globala processerna som krävs för att producera något uttryckt i enheter av samma energiform. Ju mer arbete som utförs att producera något, vilket innebär att tillgänglig energi av olika former används och något nytt arbetas fram, desto högre är det växande innehållet i det som produceras i termer av emergi. Den totala mängden av emergi nödvändig för en process blir ett mått på den självorganisande verksamhet i omgivningen som konvergeras för att göra den processen möjlig. Det är ett mått på miljöarbetet (både nu och förflytet) nödvändigt att ge en given resurs, vare sig det är träd i en skog eller ett nuvarande lager av mineraler eller olja djupt i jordskorpan eller någon vara tillgänglig på den ekonomiska marknaden. För att härleda solenergi av en resurs eller råvara är det nödvändigt att spåra tillbaka genom alla resurser och energi som används för att producera det och uttrycka varje mängd solenergi som gick in i deras produktion. Emergi mäter

värdet av både energi, materialresurser, och tjänster inom en gemensam ram, som står för konvergens av biosfärprocesser nödvändiga energitransformeringar för att producera något. Värdet i termer av emergi för en resurs är tjänsterna som tillhandahålls av naturen, som vi betraktar som gratis och utanför den monetära ekonomin såväl som tjänster av mänsklig arbete vid bearbetning av resursen.

Den teoretiska och konceptuella grunden för den här nya men framväxande metoden är grundad i termodynamik och allmän systemteori. Utvecklingen av teori under de senaste trettio åren är dokumenterad av bland annat H.T Odum (1995, 1996) och Brown & Ulgiati (2004). Emergi redovisar och i praktiken mäter kvalitetsskillnader mellan former av energi. Emergi är ett uttryck för all energi som används i de arbetsprocesser som genererar en produkt eller tjänst i enheter av en typ av energi. Definitionen av Emergi är som följer: Emergi är den tillgängliga energin (exergi) av ett slag som används i transformationer direkt och indirekt att göra en produkt eller tjänst. Enheten av Emergi är Emjoule, en enhet som hänvisar till den tillgängliga energin av ett slag som konsumeras i transformationer. Till exempel kan solljus, biobränslen, el och mänsklig service sättas på en gemensam grund genom att uttrycka dem alla i solenergi som krävs för att producera varje. I det här fallet är värdet en enhet av solenergiaktiviteten uttryckt i solemjoules (förkortad *sej*). Även om andra enheter har använts, såsom kol emjoules eller elektrisk emjoules, i de flesta fall ges alla spridande data nu i soljoule. Den totala mängden soljoule som driver en process beräknas på följande sätt:

$$Em = \sum_i f_i \times tr_i \quad i = 1, \dots, n.$$

Där Em är solemergi, f_i är den i :e i ordningen av systemets användbara inföden av energi och material, tr_i är transformiteten för var och ett av dessa olika former av inflöden.

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Emergiperspektiv på hållbar stadsutveckling

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Planerare och beslutsfattare har sedan länge försökt öka städernas hållbarhet, ofta med fokus på mer effektiv energianvändning och optimering av stadens funktioner genom tekniska innovationer [1]. Förväntningen att tekniskt avancerade, "smarta" byggnader, infrastruktur och tjänster leder till minskad miljöpåverkan stöds emellertid enligt de Jong *et al* [1] sällan av forskning, då få studier har kunnat uppvisa en korrelation mellan innovativa tekniska lösningar och faktisk minskning av resursanvändning ur ett totalperspektiv. För en mer övergripande förståelse av urban hållbarhet är det därför viktigt att inkludera omvärldsberoenden, det vill säga den externa och indirekta resursförbrukningen, som ligger till grund för och upprätthåller livet i staden. Detta är skälet till att denna studie tillämpar ett Emergi-perspektiv på urban hållbarhet, för att besvara frågan huruvida formella hållbarhetsambitioner inom stadsutveckling faktiskt leder till en kvantifierbar progression mot ökad hållbarhet.

Syfte, material och metod

Syftet med denna studie¹ var att utvärdera direkt och indirekt resursanvändning (emergi) till en byggnad och dess invånares livsstilar, genom en fallstudie i stadsdelen Rosendal i Uppsala. Rosendal var en av de första stadsdelarna i Sverige att certifieras som hållbar av Sweden Green Building Council (SGBC) [3, 4], och exemplifierar därmed empiriskt hur aktörer i Uppsalas plan- och byggprocess operationaliseras deras formella strävan mot hållbar stadsutveckling.

För att beskriva de processer som krävs för att bygga och förvalta en "grön" stadsdel, såsom Rosendalsområdet, användes Participatory Energy Synthesis, P-ES, [5]. Genom att välja en specifik byggnad: Smaragden i Rosendal [6], genomfördes PE-S som en gruppintervju med de aktörer som varit involverade i planering-, design- och byggnationsfasen av denna fastighet: en arkitekt från fastighetsutvecklaren och byggnadsarbetare från företaget PEAB. Under gruppintervjun ombads informanterna att reflektera över och diskutera de insatser och processer som krävs för att slutföra just detta byggprojekt. Post-it-anteckningar och en stor whiteboard användes som hjälpmittel, för att lista och organisera alla enskilda komponenter som använts i byggfasen, dvs materiella och energimässiga engångsinvesteringar. Samtidigt gjordes uppskattningar av de ytterligare insatser som tillkommer i förvaltningsfasen, uttryckt som konstanta flöden på årlig basis.

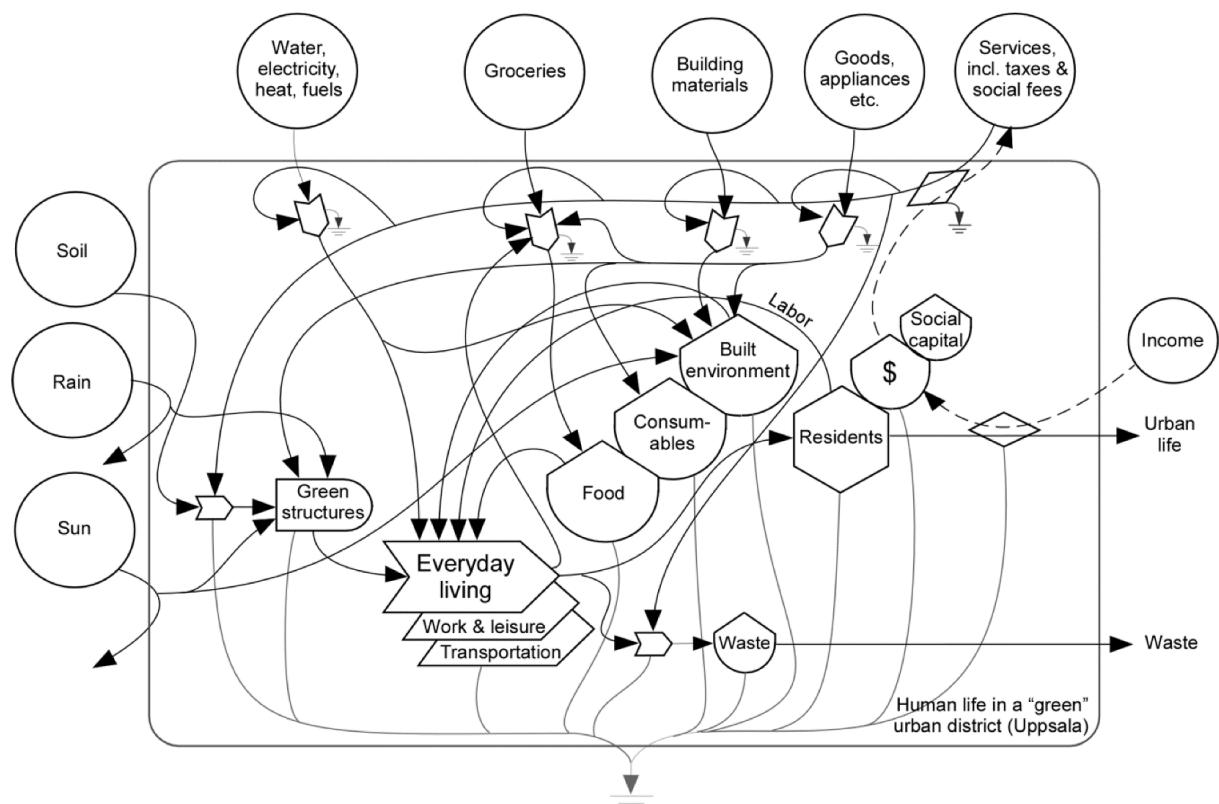
Kvantitativa data över de insatskategorier som identifierades genom P-ES erhölls sedan genom extraktion från de CAD-filer (Computer Aided Design) och plandokument som producerats av fastighetsutvecklaren och byggföretaget. Specifikt innebar detta bearbetning av anteckningar från konstruktionsbeskrivningar av byggnadsarkitekten, tekniska rapporter från tredje part som används för bygglov, och CAD-modeller, vilka exemplifieras i figur 1.

¹ Denna text är en översiktlig sammanfattning av en artikel av Bergquist et al 2020 [2]. Läsare hänvisas till denna publikation för studien i sin helhet, inklusive emergitabell och -beräkningar.



Figur. 1 Byggnaden Smaragden; arkitektonisk, elektrisk, mekanisk och strukturell modell (perspektiv från sydöst mot nordväst). Producerad med Autodesk NAVISWORKS 2019. © Felix Peniche.

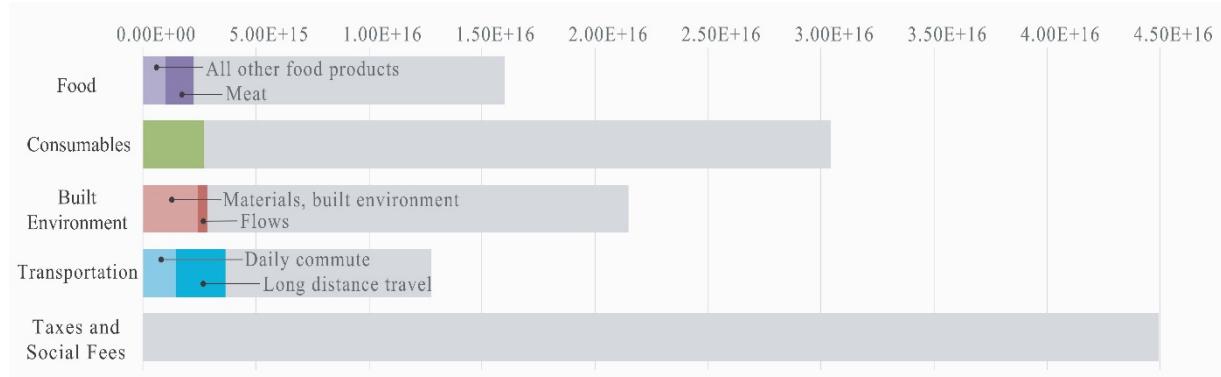
I samband med att alla insatskategorier listades, ombads också deltagarna att skissa fram ett flödesschema över interna processer och omvärldsberoenden, dvs en bred inventering och visualisering av samtliga resursflöden som krävs för att konstruera och upprätthålla den byggda miljön, förankrad i intressenternas expertis och uppfattningar. Dessa skisser konverterades sedan till studiens systemdiagram (se figur 2).



Figur 2. Systemdiagram som beskriver livet i stadsdelen Rosendal; interna processer, externa insatser och omvärldsberoenden.

Resultat; emergi-signatur

Emergi-signaturer illustrerar ett systems relativa beroende av resurser av olika slag, uttryckt i ett stapeldiagram där insatser organiseras enligt sin position i den globala emergihierarkin. Därmed visualiseras resursanvändning med avseende på både kvantitet och kvalitet, samt på ett pedagogiskt sätt som synliggör relativa andelar emergi bakom respektive underkategori. En emergisignatur för byggnaden Smaragden och dess invånares livsstil presenteras i figur 3.



Figur 3. Emergisignatur över stadslivet i Smaragden, Rosendal.

Då bidraget från lokala förnybara resurser (R) är minimalt, och lokalt icke-förnybara insatser (N) helt saknas i detta system, är samtliga kategorier i signaturen bidrag från importerade källor (F). På grund av det stora antalet specifika insatser, aggregerades dessa i underkategorierna Mat (Food), Privat konsumtion (Consumables), den byggda miljön (Built environment), Resor (Transportation), Skatter och avgifter (Taxes and Social Fees). Staplar i grått indikerar ytterligare bidrag från tjänster (services), vilka tillkommer till respektive underkategori. Skatter och sociala avgifter betraktas som en renodlad serviceinsats, och representerar de samhällstjänster byggnadens invånare har tillgång till via sjukvård, utbildning, pensionssystem etc.

Slutsatser

Hållbart boende var del av retoriken i marknadsföringen av Smaragden. Emergianalysen i denna studie ger dock en annan bild; att hållbarhetsambitionerna i Smaragden knappt skrapar på ytan vad gäller ökad hållbarhet ur ett totalperspektiv. Bland annat visar resultaten att daglig användning av el, värme och vatten – konstanta flöden – är av relativt liten betydelse jämfört med den materialanvändning som sker i byggfasen – engångsinvesteringar. Satsningen på yt-effektivt boende, ett centralt argument för hållbart boende i Smaragden, innebar i detta fall små lägenheter, under antagandet att det sparar energi och material, medan resultaten visar att det istället ökade användningen av exempelvis betong och vitvaror, till en nivå per capita som även är högre en rikssnittet.

Resultaten visade också att livsstilsfrågor är av stor betydelse för urban hållbarhet. Vid sidan av, och relativt sett högre än byggnadsemergi, var de enskilt största kategorierna i fallande ordning: (1) Långväga resor; (2) Hygienartiklar; (3) Bilanvändning; (4) Kötkonsumtion; (5) Sportutrustning och verktyg. Dessa aspekter av stadslivet har samtliga att göra med hur mänsklor lever, snarare än hur de bor.

Resultaten från denna studie indikerar således att satsningen på trendiga, effektivitetsorienterade så kallade "smarta" lösningar för energieffektivitet, såsom i Smaragden, är av begränsad nytta för att uppnå urban hållbarhet ur ett brett system-perspektiv. Om inte större insatser görs för att minska omvärldsberoenden, och framförallt använda en större andel lokala förnybara källor, kommer bidraget till hållbar stadsutveckling att vara försumbar.

Diskussion

För att diskutera systemets övergripande prestanda och förbättringspotential, beräknades ett urval energi-index som beskriver systemet ur ett globalt emergiperspektiv. Till exempel har Doherty *et al* [7] tidigare uppskattat den teoretiska maximala befolkningen som kan upprätthållas på förnybara resurser i Sverige; den förnybara bärkapaciteten vid nuvarande levnadsstandard. För att beräkna detta används GREC (Global Renewable Energy Constant) som utgångspunkt, vilken uppskattar den produktiva kapaciteten på årlig basis och planetär skala. När denna globala energi-”budget” divideras med världsbefolkningen, beräknas den teoretiska tillgången till globalt förnybara resurser per person och år, uttryckt som SolarShare [8].

Eftersom denna studie beräknade total energi per person och år, kunde en jämförelse alltså göras mellan de boendes faktiska energi, och deras rättvisa andel av globalt tillgängliga resurser. Beräkningen visade att det teoretiska värdet SolarShare ($1.63 \times E+15$ sej/capita) ligger två tiopotenser lägre än energivärdet för Smaragdens boende ($1.26 \times E+17$ sej/capita). Solar Cost Index (SCI) är benämningen på det index som uttrycker detta glapp mellan tillgänglig och faktisk energi [8], det vill säga en jämförelse av energi bakom en vara eller tjänst (i denna studie, stadslivet i Rosendal) och SolarShare. En SCI större än 1 indikerar således en livsstil som tar i anspråk mer energi/capita/år än som är teoretiskt tillgängligt på global nivå. I denna fallstudie beräknades en SCI på 77,29, vilket indikerar att snittinvånaren i Smaragden använder ca 77 gånger mer än deras rättvisa andel av globalt tillgängliga förnybara resurser.

Detta innebär att, för att stadslivet som i Smaragden ska vara hållbart, kan samhället välja mellan två fundamentalt olika vägar framåt: (1) minska den globala befolkningen för att göra plats för den livsstil som för närvarande åtnjuts av en minoritet i Uppsala; eller (2) minska resursanspråket med en faktor på 77,29, för att möjliggöra en rättvis andel av tillgängliga resurser för den nuvarande världsbefolkningen på 7,44 miljarder. Denna studie lyfter således känsliga, men viktiga och underutforskade etiska överväganden beträffande människors förmåga att konsumera mer än sin rättvisa andel av resurser, beroende på var de bor, och framför allt, hur de lever sina liv.

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An analysis of the Energy-related concepts Energy, Exergy and Embodied Energy and in what way they reflect environmental load

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Abstract

To analyse a system from an environmental/energy perspective, different conceptual indicators can be used as a base. This is a short presentation of the thermodynamic concept Energy, in comparison with Energy, Exergy (Work energy) and Embodied energy and how they reflect an “energy memory” or historical energy use in a resource/matter. From a thermodynamic perspective Energy has a clear definition referring to what 1 J actually is. The energy unit 1 sej is more difficult to capture, but can be viewed as an attempt to reflect the total energy input (based in solar radiation). The Exergy value in matter is thermodynamically defined as energy stored in the molecular structure. The idea to use this as an indicator of environmental load is logical in the sense that the energy stored in the structure needs to correspond to the energy needed to shape the structure, but of course it does not say anything about the efficiency between input energy and stored energy. Embodied energy is often defined as the energy needed in all the processes involved in a production process (or similar). It can be compared to an LCA energy value of matter. The embodied energy is thus the sum of inputs following a production process. It is in way part of the Energy value for the same process/matter, disregarding primary energy input (solar radiation) and normally labor and other indirect consumers. From an engineering perspective there are no limitations in the use of energy in an analysis. Using the Energy concept means we transfer measures of energy as Joule into sej, and it is more difficult to follow the actual process energy efficiency. By applying the Energy concept we might be able to capture a “philosophical dimension” as a quantification of an energy memory in a system resource, but the drawback is we cannot use the quantification and relate to the physical reality when it comes to analysing alternative system efficiencies. The aim with an analysis is the base for the choice of suitable indicator. My conclusion is that an Energy analysis is interesting, but often lacks direct relation to the basic engineering concepts when it comes to detailed analysis of the system efficiency as a base for improvements or comparisons of alternate use. I therefore find it difficult to find applications for how to use the results from an Energy analysis, which probably is due to my engineering background and the fact that my references are the normal energy concepts.

Introduction

With a long background in engineering, I entered some years ago the world of valuation of environmental load by using sustainability indicators. There are many different ways to quantify environmental load and depending on the aim with the analysis, different methods and indicators give different perspectives. My ambition here is to give a brief view of concepts related to energy indicators, to clarify in what way they reflect environmental load, especially Energy referring to the focus of this seminar, and its relation to Energy, but also the concepts Exergy and Embodied Energy are of interest when it comes to quantifying environmental load.

The starting point for my reflection will be the engineering view of an energy analysis and from this viewpoint, to compare this with an Energy analysis. I will use steel production as an example since iron ore is part of the flow, and the analysis of energy input to produce ore will differ a lot depending on method used, thus clarifying the differences in approach. The iron ore will also be used to discuss the concepts Exergy and Embodied energy. Steel also has another advantage, simplifying the analysis; it

does not contain living matter. If one has the ambition to quantify living matter in a way differing it from dead matter, this introduces another complexity which has to be dealt with another way compared to a direct input-output analysis of flows of energy. For living matter the problem will be how to deal with differences in concepts involved, and even if a quantifying value can be presented, the interpretation in terms of relation to the physical world will be difficult to judge (and value). The ambition to quantify living matter in relation to dead matter in terms of energy might be interesting, but difficult since energy as a base is not suitable for this quantification.

My impression why such concepts such as Emergy, Exergy and Embodied energy have been introduced, is that they all have a base in an ambition to capture an "energy memory" stored in the material. To quantify this "memory" we somehow have to be able to value the actual input energy used in the creation process of the material. It is not obvious when and how such a memory is to be used in an analysis, and in what way the information is useful. However, just to regard for example coal as "free of charge" to use does not tell us anything about the actual "sustainability indicator" of the material. Coal, petroleum etc are limited resources, and one way of quantifying the "value" from a sustainability perspective, is to judge the energy input in the creation process. The concepts highlighted in this presentation will be described from a sustainability perspective.

Beginning with the engineering perspective, but without going too deep into the physics and chemistry, we know there are different kind of energies:

Potential energy ($E_p=mgh$, as the potential energy of an elevated mass)

Kinetic energy ($E_k=(mv^2)\cdot\frac{1}{2}$, as mass with the velocity v)

Chemical energy (the energy contained in chemical bonding in a molecule, typically released in decomposition such as oxidation)

Inner energy ($U=E_k+E_p$ for the molecules in a system)

Atomic energy (released in a nuclear process and related to $E=mc^2$, but typically in a nuclear reactor only part of the available mass energy is being used in the reaction $n + {}^{235}\text{U} \Rightarrow {}^{236}\text{U} \Rightarrow {}^{93}\text{Rb} + {}^{141}\text{Cs} + 2n$)

Radiant energy (typically heat, light and electricity)

These different forms of energy still do not explain what energy actually is. When we quantify an energy amount as "Joule" or "Calorie" it is not for sure we know what this means. In thermodynamics 1 calorie (cal) corresponds to the amount of heat that needs to be transferred to a system that contains 1 g 14,5°C water, to be able to increase the temperature of this water system to 15, 5°C. 1 Joule (J) is defined as the work needed to move the force 1 Newton (N) 1 meter (m) in the direction of the force, which corresponds to 1 Nm. Heat and work are different forms of energy, but can be expressed in the same units since they are in different ways transferrable to each other (1 cal ≈ 4,19 J (or Nm)) (Appelqvist, Frössling, 1979).

An energy analysis of a system

To begin with we can look at an typical historical steam machine and study it from an energy perspective. From an old Swedish Encyclopedia I have found some efficiency values for the development of the steam machine (Nordisk Familjebok, 1922). Newcomen's machine around year 1700, needed typically 10-20 kg coal to produce 1 hp-h (horsepower-hour) as kinetic energy, which corresponds to 2,6 MJ. The available energy in coal, in an oxidation process, is about 30 MJ/kg and 15 kg coal corresponds then to 450 MJ. The efficiency in Newcomen's machine was in other words around 0,5%. However, the development of the steam machine increased the efficiency with Smeaton's innovations (around 1750) resulting in an efficiency about 1% and Watt (around 1770) doubled the efficiency again to 2% so only 4 kg coal was needed to produce 1 hp-h. This is a typical mechanical thermodynamic example with energy input, energy output and definition of efficiency as the share of output of energy needed (in this case kinetic) divided with the input as available energy from an oxidation process. The efficiency tells us something about the use of the input resources in relation to the wanted output as another form of energy.

Let us instead study a cow as if it was a machine, which of course is a typical engineering view, but this is done only to simplify the analysis of energy flow in the thermodynamic system "cow". The input resource is typically hay and water (disregarding other feed). The output of major interest for the owner of the cow is in this example milk. The energy transfer can be simplified as an input of hay with an available energy for the cow around 11 MJ/kg (as DM, dry matter). If we instead would feed the hay into an incineration process, the available energy would be set to 19 MJ/kg, which is lower than the available energy in coal reflecting the carbon content of the respective materials. Human beings cannot break down cellulose, thus making the available energy content in hay as food for humans very low. When we study a system in an energy perspective, we need to have the aim with the analysis clear in mind. The efficiency of the system studied will vary with the way we look upon the availability of the energy in the input resources, just as the output energy form. If the cow eats about 30 kg hay per day (plus water) and give 30 kg milk, the input would be about 300 MJ and the output as milk 50 MJ (milk contains about 1,7 MJ/kg). The energy efficiency is thus 15-20% measured at the input as available energy for the cow, and as output available energy for a human being. If the input value instead would be the available energy in the hay in an incineration process (19 MJ instead of 11 MJ), the efficiency would drop to about 10%. The oxidation process (incineration) can extract more energy out of the hay compared to what the cow can do and if this kind of relativizing is interesting for us, this is an alternate way of setting up the balance. What is important is that we have the purpose with the analysis clear in mind.

We can expand the system "Cow" to be part of the system "Agricultural sector" as a whole, with a set of farmers, machines, animals etc. This will no longer be a separate thermodynamic system, but rather just a system as a set of subsystems, which in turn can be studied as thermodynamic systems. Without going into details, the agricultural sector of the county Jämtland produces an output of about 480 TJ food measured as available energy for human beings. The input is 500 TJ renewable energy (as electricity and biodiesel) and 510 TJ non-renewable energy (petroleum products, typically fossil diesel). An efficiency of just below 50% is very high for such a complex system, but what is not calculated is the solar radiation input of about 14.000.000 TJ turning our system into an extremely inefficient machine. The photosynthesis has a very low efficiency, thus making the process from solar radiation to cellulose performing in line with an old steam machine (maybe around 1% efficiency). But if we really want to know the total efficiency in the complete system from solar radiation to milk, we can find reasonable values for such an analysis. However, the approximations in solar radiation input and difficulties to specify exact efficiency of the photosynthesis process, makes other energy input uninteresting.

Expanding the system to include input of solar radiation needed for the fuels and electricity used in the agricultural sector, as a historical "energy memory", makes it possible to analyse our system from a perspective of total energy input of energy. Such analysis might be interesting to value the "actual" energy needed to produce 1 kg of milk for example. At the same time the calculations will lack exactness and be rather philosophical since we cannot really translate the energies into alternatives.

One interesting comparison is the efficiency of land use, looking at available energy from solar radiation. Referring to the low efficiency of the photosynthesis (around 1%), the transformation of solar radiation energy to electricity will be more efficient (around 20%) compared with the production of for example biodiesel. Again, we need to take the production of the solar panels, cables etc into consideration as well. But the biodiesel also needs surrounding systems to be analysed from an energy efficiency perspective.

An analysis of the production of steel based in energy use

To produce a steal beam, several production steps are needed: Mining of the iron ore and coal for the process in the blast furnace using different energy sources such as fuels and electricity, to produce pig iron. The pig iron is the raw material used for the steel manufacturing in a basic oxygen furnace, or an electric arc furnace, again adding a lot of energy. In the rolling process different end products are manufactured, which also needs energy input. All these stages need transportation, human labor etc.

This can be studied different ways. **Fel! Hittar inte referenskälla.** below shows an example with an energy analysis of for the complete process of China's steel manufacturing.

Component	Electricity (GWh)	Fuel (TJ)	Final (TJ)	Primary (TJ)
Reported energy consumption (excl below)	174 293	8 593 558	9 221 013	10 515 967
Energy for production of coke	5883	488 395	509 574	553 283
Energy for production of net exp of pig iron	-114	-13 412	-13 822	-14 669
Energy for production of net imp coal-based DRI	42	4934	5085	5397
Energy for production of net imp of steel ingots	17	1589	1650	1776
Energy for production of net exp steel billets	-2082	-192 304	-199 799	-215 268
Total energy consumption with embodied energy	178 039	8 882 760	9 523 701	10 846 487
Incl net imp/exp of auxiliary/intermed products				

Table 1 Total energy consumption of China's Steel industry production 2006 (Hasanbeigi et al, 2014, table 9).

What is the use of the analysis made by Hasanbeigi et al presented above? Well, for several reasons this might be interesting. The writers have made a comparison between China's and USA's production processes concerning energy intensity (see **Fel! Hittar inte referenskälla.**).

Country	Electricity intensity (kWh/t)	Fuel intensity (GJ/t)	Final energy intensity (GJ/t)	Primary energy intensity with T&D losses (GJ/t)
USA	675,8	12,5	14,9	20,0
China	431,7	21,5	23,1	26,3

Table 2 Energy intensity of the iron and steel industry in China and USA 2006 (Hasanbeigi et al, 2014, table 10). The units kWh/t and GJ/t refers to energy intensity per ton crude steel.

Now, this is a typical application of an energy analysis of a technical process. Returning to the idea of including the "energy memory" of the raw materials, Buranakarn (1998) has made a so called Emergy analysis (Odum, 1996) of steel, comparing conventional steel (as above) with recycled steel. In the Emergy analysis, the input energy into the resources (energy and matter) used are included. From the discussion above about the photosynthesis process, the calculations lack precision, however as long as the same factors are being used for transforming specific matter or energy into another in all analysis, comparisons can still be made. Buranakarn present a table (see **Fel! Hittar inte referenskälla.**), that serves as an example for such an analysis.

Note	Item	Unit	Input resource	Solar emergy (sej/unit)	Emergy (1,00 E+20 seul)
A. Conventional steel product					
1	Pig Iron	g	4,53 E+13	2,83 E+9	1283
2	Natural Gas	J	3,17 E+17	4,80 E+4	152
3	Other fuels	J	2,80 E+16	6,6 E+4	18
4	Electricity	J	1,84 E+17	1,74 E+5	319
5	Transport (railroad)	Ton-mile	7,50 E+9	5,07 E+10	4
6	Transport (truck)	Ton-mile	7,50 E+9	9,65 E+11	72
7	Labor	\$	1,58 E+9	1,20 E+12	19
8	Annual Yield	g	4,49 E+13	4,15 E+9	1868

B. Material recycling steel product					
9	Post-consumer steels	g	4,53 E+13	2,83 E+9	1283
10	Post-consum. steel collection	g	4,53 E+13	2,51 E+8	113
11	Post-consum. steel separation	g	4,53 E+13	8,24 E+6	4
12	Natural Gas	J	3,17 E+17	4,80 E+4	152
13	Other fuels	J	2,80 E+16	6,6 E+4	18
14	Electricity	J	1,84 E+17	1,74 E+5	319
15	Transport (railroad)	Ton-mile	7,50 E+9	5,07 E+10	4
16	Transport (truck)	Ton-mile	7,50 E+9	9,65 E+11	72
17	Labor	\$	1,58 E+9	1,20 E+12	19
18	Annual Yield	g	4,49 E+13	4,15 E+9	1983

Table 3 Emergy evaluation of steel and steel recycling alternatives (Electric arc furnace process) (Burankarn, 1998, table 3-4)

The analysis is thus made with the input resources (including labor in monetary units) in its SI-units, thereafter a recalculation factor (Solar energy per unit, sej/unit) is used to transform the SI-units into Emergy (sej). The recalculation factor (transformation factor) is taken from pre-calculated tables, typically with the origin of Odum (1996, p 304-311), and in some cases updated. What is gained in simplicity using the transformation factors, is of course lost in precision. In Buranakarn's analysis, the recycled steel get a higher Emergy value compared to the conventional steel (from pig iron), since he does the analysis "according the book" applying the logic of analyzing the whole chain. Row #9, Post-consumer steels, has the same value 1283 sej as the input of pig iron into the conventional product (#1). This part can of course be excluded to get the Annual yield for the recycled steel of 700 sej , to be compared with 1867 sej for the conventional steel, indicating the recycled steel needs less than 40% of the total Emergy compared to the conventional product, disregarding the pig iron. The idea with this kind of Emergy analysis is to find a way to value input resources in terms of total "energy memory", to prevent non-renewables (typically fossil resources) to be included as resources with a very low "energy memory". The dilemma with the unit sej , is that there are no clear references to energy values, thus making it impossible to directly compare with other data if not Emergy based. One important aspect with calculated values is the ability to make comparisons. However, such comparisons can of course be done between different Emergy analysis. The aim with the analysis is again most important to clarify. Of course "energy memory" in resources can be calculated other ways, if this is of main interest. Unfortunately, to talk in the perspective of an Emergy analysis, most of the time we are not very interested in such a memory since we are looking for simplifications and clarifications referring to the actual processes involved. Furthermore it is unclear how mechanical pressure can be defined as part of the energy needed to form coal, oil, natural gas etc. How is the result of such an analysis affected by the uncertainties in energy input? The output from the steel analysis made by Buranakarn, 4,16 G sej/kg for sure tells us something about the resource input, but what does it tell us? The analysis made by Hasanbeigi et al gives the output (for China) of 26,3 MJ/kg as primary energy intensity. We can make an analysis of the climate impact from the production of the electricity for example, which not is as clear using the sej/kg unit.

One claimed strength with an Emergy analysis is the possibility to include for example labor as monetary unit (\$), transformed into sej . However, the same calculation principle can be applied in an energy analysis, finding a factor for a country's total energy usage in relation to GNP. I would however hesitate to say if this really reflect the energy use of labor. It might be better to calculate the actual energy usage for a human being per working hour, or calculate the work needed and use the efficiency of the human muscles (typically 20%) to find the input, which in turn can be included in a wider system if solar radiation of food are to be taken into consideration. However, the flexibility with a "conventional energy analysis" set high demands of structuring the calculations and keep control of the system

boarders. An Energy analysis is based upon a precalculated set of transformation factors. The result will be very approximative and for at least “technical” purposes the value of the Energy analysis result can be questioned.

Work energy (exergy) and Embodied energy as measures of “Energy memory”

To somehow capture the value of an energy memory in a flow analysis, sometimes the work energy (exergy) is being used. The method is pointed out as being developed to give a “strong and robust physico-materialist basis to the definition of sustainability” (Nielsen & Jørgensen, 2015, p. 14). The idea is that the work energy content in a material makes it possible to transfer a weight of a specific matter, into an energy measure that capture the “energy memory” of the material. However, the work energy (available energy) stored in matter does not say anything about the efficiency in the process from for example solar radiation to crystalline structure in iron ore. On the other hand it is in some sense a more specific (physical) value. Taking hay again, the work energy is about 19 MJ/kg and this is actually the amount of energy possible to get out from an oxidation process. By using the work energy we can compare different usages of a resource in terms of over-all efficiency. A cow can extract 11 MJ/kg from the hay and an incineration process 19 MJ/kg. Of course the processes involved have losses which have to be taken into consideration. Using work energy as indicator makes it possible to study systems at different levels from an energy efficiency perspective. But it is necessary always to bear in mind that the work exergy is not necessarily available in an engineering sense, and taking the steel example from above, it can be a bit complicated to deal with flows of steel at a societal level. What does it for example mean that steel has a content of work energy? Recycled steel to be melted need energy input (high power electrical electrodes are being used normally) so in what sense can we say the work energy of steel reflects something useful? It rather reflects the energy needed to melt the steel than something we can transfer into useful energy.

The concept “embodied energy” does not have a clear definition and the meaning has varied throughout the years. In principle the idea is to capture the “energy memory” from the processes involved to shape the material/resource. It appears as if the meaning once was similar with the energy concept, thus (sometimes) including also the primary energy input needed (solar radiation). Today this primary part seems to have vanished in most usages of the concept, and embodied energy gives an approximate value of the energy memory of human created processes. This value representing an environmental load thus can be said to correspond to the energy part of an LCA for a resource. For system analysis purposes of material flows, efficiencies in recycling etc, the embodied energy/LCA value is rather useful and easy to understand. The work energy value is neither a true energy value, nor representing an energy memory from a specific point in the historical flow.

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Energy and water – findings from Cyprus' and Sweden's water balances

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Introduction

As an extension to a project of assessing the sustainability of water use in Cyprus (Paschali, 2019), data for Sweden has also been collected and processed. In figure 1 are presented the water balance for Sweden and Cyprus. The fundamental flows of water reaching Sweden and Cyprus described in the two diagrams include water entering as precipitation, inflow from neighbouring countries (where applied) and flowing out through evapotranspiration and outflow to the sea and neighbouring territories.

Energy and Water

The energy available in water is in energy accounting calculated in two ways. Firstly the physical energy – use of the gravity potential between the rain entering the system and the sea level where no more gravity energy is converted to movement energy or other energies, useful to humans or other subsystems of the ecosystem. Second the chemical energy – use of the chemical potential in the water. The possible chemical reactions with substances in the soil, in the photosynthesis processes in plants, as well as chemical reactions in industries and households. This energy, in traditional energy accounting, is estimated by using the osmotic potential difference between rainwater and saltwater calculated by Gibbs free energy on Seawater (Odum, 1996). This is the difference reduction in the water when dissolved elements increase in the water on its way from the mountains to the plains and finally mounts in the sea. A lot of the osmotic potential is still there when rivers meet the seawater which is used up by the very productive estuary ecosystems.

In energy accounting –energy algebra (Odum, 1996) – a central choice needed to make, is if the energy flow should be treated as a split or a coproduct. A split is "...branches that split into two flows of the same type...", while coproducts (also called by-products) are "...branching transformations that produce flows of different types" (Odum, 1996).

The splits keep the same transformity for both branches, and the division of energy follow the energy content and is diagrammed as pathways branching without associated energy transformations. Coproducts have different transformities for both branches, all branches carry "...the same energy (the full amount coming in)" (Odum, 1996), and if "...the branches come together again, [they are]...not to be added because it is realized that the two sources are not independent." For coproducts, an energy transformation symbol is used (producer, consumer, interaction, miscellaneous box).

Regarding water, it is clear that water streams are treated like splits, for surface water, groundwater, or water in pipes. It is also clear that when water goes into a chemical reaction, like in photosynthesis or industrial chemical reactions, water energy is treated like coproducts. Then there is a grey zone, not yet fully sorted out, regarding the minerals dissolving in the water, or when suspended particles are carried by the water. This is, of course, even more significant in wastewater. In the grey zone, is also the water carrying heat content, e.g. in cooling applications and similar.

Energy findings for the Swedish and Cypriot data.

Evapotranspiration in Cyprus in 2017, as we can see in the diagrams, is higher by almost 40% compared to Sweden. Most water flowing internally, in Sweden, is outflowing in the sea and some water

(1%) is outflowing into neighbouring territories. Whereas in Cyprus, most water flows internally and appears to remain, only some (31%) outflows in the sea.



Figure 1: Water balance flows of (A) Sweden and (B) Cyprus for the year 2017 based on Eurostat data.

Discussion

Regarding the principal question of split or coproduct for dissolved substances in water, it seems like coproduct is a more suitable choice since it is a chemical reaction producing ions taking place.

The energy properties of water appear to change to some extent. Regarding suspended solids, the split approach seems more relevant, since no energy conversion appears to be involved. And as for heat content, the same can be said. In both Cyprus and Sweden the dominating accounting choice are splits, but also some coproduction (e.g. in soil reaction, photosynthesis and chemical reactions in industries). Cooling water split since the water itself is not changed, just its heat content. The same applies to desalination, water content split, but if the desalination plant is in focus, it is a coproduct process.

If the heat processes of conduction and convection, is regarded as involving no energy conversion it should be treated as a split. Heat energy seems to have a special position compared to other energy forms.

Regarding rivers, maybe it could be useful to think of like a similar approach to a heat exchanger device in the rivers, where the salinity increases more close to the seawater. This since the difference in sea salinity is very different for Sweden ie.- on the west coast, Kattegatt, salinity amounts for 3.5% whereas in the northern part of the Baltic Sea on the east coast it is only approximately 0.3%.

Conclusions

For energy and water, there is no doubt that water streaming, whether surface or groundwater, should be treated as a split, while chemical reactions with water molecules involved are clearly of the coproduct type. Regarding the application of dissolved substances of different types, suspended solids, and also heat content and exchange in water, seem to be in a grey zone still.

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Energy – providing the basis for a more equal world?

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1. Introduction

The world today is a place of growing inequalities, both within countries and internationally. The UN Sustainability goals are set to be reached by 2030 and goal number 10 addresses the issue of inequality (*About the Sustainable Development Goals - United Nations Sustainable Development*, n.d.). Yet we are far away from reaching it. The overall life quality has increased for many people in emerging economies, but this development is happening at the same time as rising wealth concentration among the richest in the world (*World inequality report 2018*, n.d.).

International trade is a contributing factor to the problem. It is driven by a goal of expanded production and consumption without much interest in the public good (Beder, 2006). Free market policies intensify trade inequities and causes environmental stress (Odum & Odum, 2001). Put in the words of Weizsäcker & Wijkman, “Almost by definition, free trade does help the strong and harms the weak” (2018, p. 37). The following text will look into trade with natural resources and aims at giving an explanation to occurring inequalities by using the logic of H.T Odums concept *emergy*. It will also show what solutions this might hold to reach a more equal world on several levels.

2. Energy and Real Wealth

The Energy concept was founded by American ecologist H. T Odum with the aim to give a more comprehensive and adequate value to ecosystem goods and services (Woora & Thrift, 2010). Traditionally the value of goods and services are decided by the market in monetary terms. The price is set relative to the amount that is available and fluctuates with scarcity or abundance. Money is however only a measurement of what people are willing to pay for products and services and it is only paid to humans for the processing services they put in. The circulation of money that takes place among humans is how we define the world economy, but this is insufficient since money does not evaluate the direct contribution from the environment (Odum, 1996). Energy measures *real wealth* which are the products and services that we use such as food, clothing, fuels, minerals, forests, buildings, music, art and information (Odum & Odum, 2001). The reason for its superiority is the way energy measurements incorporates the work of nature as well as the work of humans, previously required to generate a product or service (Brown & Ulgiati, 2004). This is done by capturing the energy value in the resource consumption behind a product or a service, expressed in solar equivalent joules (sej). Sej is convenient since it makes it possible to express energies of different kinds in a single unit (Odum, 1996).

Another helpful addition is that solar emjoules can be connected to the global economy. This is done through the energy/money ratio. Odum (2001) explains it by looking at the example of a country. The energy/money ratio is given by calculating the real wealth (energy use) of that country in solar emjoules per year. It is then divided by its Gross National Product. This measurement of energy per unit money-shows the average buying power of money regarding energy (real wealth). It is not buying power in a traditional sense, it rather shows how much *sej* comes with every unit of money.

Table 4 National activity and Emergy/Money Ratio. Data for 1980-1987. Adopted by Odum (1996 p. 201).

Nation	Emergy used per year ($\times 10^{20} \text{sej/yr}$)	Gross Product ($\times 10^9 \$/\text{yr}$)	National Emergy/Money Ratio ($\times 10^{12} \text{sej}/\$$)
Ecuador	964	11.1	8.7
India	6,750	106	6.4
Netherlands	3,702	16.5	2.2
USA	83,200	2,600	3.2

As seen in Table 1, every country has their own emergy/money ratio, and this makes it possible to evaluate the real wealth benefits of international trade and financial exchanges (Odum, 1996).

3. Energy and trade

3.1 International trade

When conducting international trade, it is often assumed that market prices ensures a fair exchange. However, since money does not measure real wealth and fails to incorporate the work done by the environment, it is clear that market prices underestimates the real wealth value of raw commodities (Odum & Odum, 2001). With emergy accounting it is possible to point out the benefits and losses of international exchange (Odum, 1996). When trade with environmental products are conducted between rural states and more developed economies, there is a large net emergy benefit to the developed buyer. To exemplify this Odum (1996) shows the unequal exchange of wealth between USA and what he refers to as 'Resource country'.



Figure 1 Exchange of Real wealth in solar emergy. Adopted by Odum (1996 p.211)

The buying power of the U.S dollar at the time (1985) was about four times what an international dollar would buy in a resource country. He could show that when transactions between the countries took place, 8 billion *sej* was 'gained' in favour of USA for every dollar paid to resource country and in

reverse only 2 billion *sej* was gained for every dollar paid to the U.S by that same country. In other words, USA earned four times as much emergy (*sej*) for every exchanged dollar (Odum, 1996). This phenomenon can be explained by two things; 1) the emergy value of environmental products are higher than that in the money paid for the processing services, 2) the emergy/money ratio is higher in the rural state supplying the product than in the developed economy. This is because they tend to have lower GDP and more of the wealth goes directly from the environment to the human consumer without money being paid (Odum, 1996).

3.2 Domestic trade

The particular trend of growing inequalities between rural and urban areas are demonstrated worldwide both in countries such as China (*World inequality report 2018*, n.d.) and Sweden (Björling & Fredriksson, 2018). Concentration and centralisation of power as well as negative effects on the environment can be seen as a consequence of growing urbanization (Brenner, 2013; Díaz et al., 2018). These effects on nature is characterized by a linear flow of resources towards cities which leads to depletion of agriculture land and exploitation of natural resources and ecosystems (Díaz et al., 2018). Looking at Sweden, one of the explanations given for increased inequality is the shift to a more market

oriented system which successively have shifted the focus of spatial planning from distribution of resources to increased competitiveness (Björling & Fredriksson, 2018).

(Grönlund, 2008) and Grönlund & Samuelsson (2009) have done emergy calculations for trade within Sweden which offers a clearer image of the inequalities in terms of real wealth. They have looked at trade between the urban capital area and northern rural 'resource' areas. Their results follow a similar trend to that of Odum and shows an uneven exchange of emergy for every generated SEK (Swedish krona). For every generated SEK, the capital area gained 2.5 times as much emergy (Grönlund & Samuelsson, 2009). While pointing out the uneven exchange the authors emphasize that there is no aspiration for an even exchange within countries which makes 'generated SEK' the appropriate term.

4. Discussion

An unequal society affects us all both directly and indirectly. Many people suffer from it directly where their ability to improve their lives or have influence on how to change it becomes smaller. The deterioration of the environment will ultimately affect us all even though people in poverty has the worst end of this too. The economic system amplifies the power balance in the world, leading to an accumulation of wealth to a smaller number of people and moving the power away from governments into the hands of transnational corporations. The role of money has grown out of proportion to what is really important. At the end of the day money is only a measure of how much people are willing to pay for something. It relies upon a belief that something is valuable, and this can change from one day to the other. However, since money has become equal to power the current system is set up for inequality and destruction of the environment. Looking through the lens of Odum's logic it can be argued that rural areas or resource countries can't compete with today's terms since the services contributed by them include hidden emergy contributions of the free commodities they use (Odum & Odum, 2001). The real wealth of natural resources is not shown which gives urban areas or developed countries unfair attention and advantages. At the end of the day most of us would agree that in a real crisis a field of crops, a lake filled with fish or a forest would be more valuable than any number on the bank.

The concept of real wealth is very fitting since it does not consider the status of brands or of power relations, it is based on a steadier ground. According to Odum it puts everything on a common basis; resources, products from the economy, components of the environment, human assets and the intangible contributions of humanity (2001, p. 281). If the value of resources would be reclaimed it would be beneficial for countries to use them more wisely. This is what we need in order to break the pattern of world development. If the attention of the international agenda was less focused on money and instead looked at the real value behind what is being traded the world would see greater global benefits both for the humans populating it and the environment. Because the idea is not that inequality should shift the other way around. Odum advocates for capitalism to be replaced by cooperation among nations and cooperation with the environment.

The cooperation with the environment leads us into another important part of Odums reasoning. Emergy offers a much missed ecocentric value to the debate on ecosystem services. With Odum's concept of real wealth, he refers to a systems value which places intrinsic worth on the natural environment and its living organisms. This can be contrasted with the traditional monetary valuation which gives value to single persons and hold an anthropocentric view (Grönlund et al., 2009).

A big shift in perception is required to make this happen. We need to move from individualism to collectivism, from an anthropocentric view to an ecocentric. This is not something that can be expected to happen fast but a good first step is to reclaim the value of nature and to start looking at perceptions and values of progress differently. Energy valuations could play an important part in reassuring fair trade both domestically and internationally. It could be a helpful tool in the shifting of perception and hence be the way towards a more ethical world, for humans as well as for the environment.

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Energy view on sustainability compared to environmental science textbooks' views on sustainability¹

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Abstract

Emergy analysis (energy synthesis) is one of the methods in the sustainability assessment toolbox. In the way it is using stocks and flows of energy and matter it is similar to Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Substance Flow Analysis (SFA). However, Emergy accounting also includes stocks and flows of money and information. In its mechanism of relating to a global baseline of renewable flows Emergy accounting is similar to Ecological footprints in that it is not just revealing which of two alternatives is using more or less of different stocks or flows but also comparing the use to available renewable flows on a global annual basis.

This paper compares, from a modelling perspective, different sustainability approaches covered by Emergy analysis, with more general views on sustainability and sustainable development based on a selection of sustainability textbooks. For the areas not yet covered by energy analysis, conceptual model approaches are suggested.

The four different approaches of assessing sustainability identified were: 1) the Energy Sustainability Index (ESI), 2) emergy as a normalizing measure, 3) emergy as a network measure, and 4) the pulsing paradigm. The general aspects from textbooks were presented as three pairs of paradigm views on sustainability: 1) Strong and weak sustainability, 2) Malthusian vs. Cornucopian view, and 3) the "funnel" vs. "cylinder" sustainability paradigm. It was found that the strong sustainability, the Malthusian view, and the "funnel" paradigm were already to a significant extent covered by the existing energy approaches. The new suggested conceptual models included capital substitution for weak sustainability, ingenuity and innovation for the Cornucopian view, and the choice of presentation to clarify the view for the "funnel" vs. "cylinder" paradigm.

Keywords: ecosystem ecology, sustainable development, capital

1. Introduction

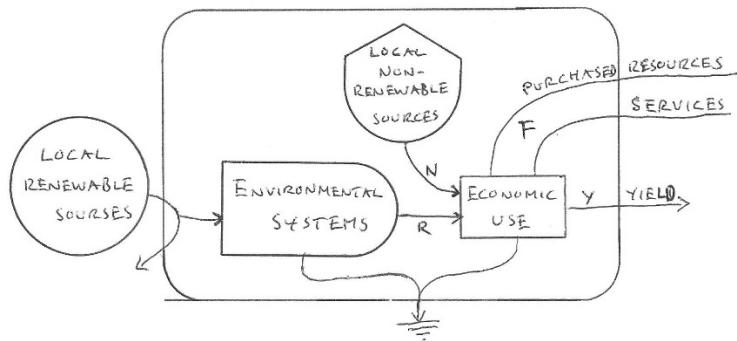
1.1. Emergy accounting

Emergy accounting is one of the methods in the sustainability assessment toolbox. The method is using stocks and flows of energy and matter similar to Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Substance Flow Analysis (SFA). However, Emergy accounting also includes stocks and flows of money and information. In its mechanism of relating to a global baseline of renewable flows Emergy accounting is similar to Ecological footprints in that it is not just revealing which of two alternatives is using more or less of different stocks or flows but also comparing the use to available renewable flows on a global annual basis. The latest global energy baseline was calculated to 12.0 x 1024 sej/year (Brown et al. 2016).

¹ Based on a presentation at the International Society for Ecological Modelling Global Conference 2019, 1st - 5th October 2019, Salzburg, Austria

1.1.1. Emergy and the Energy Hierarchy Principle

Emergy is a measure that emerges when the energy hierarchy principle is applied to natural systems (e.g. forests, meadows, lakes and rivers) or human systems (e.g. cities and countries). The principle postulates that energies in any system will self-organize in hierarchical patterns given time to do so (Odum, 1994, 2007). Emergy is expressed in relation to one type of energy occurring in the hierarchy, almost always solar equivalent joules (sej). In the context of economy, emergy values can alternatively be expressed in a currency related unit, for example Em€ or Em\$ (proportional to values in sej). The significance is that Em€ or Em\$ measures the contribution different items gives to the whole system, rather than how individuals value different items on the market; a donor value approach rather than a receiver (market) value approach (see e.g. Odum 1996; Grönlund et al. 2015). Emergy accounting use many different indices (Brown and Ulgiati 2004) based on stocks and flows of renewables (R), non-renewables (N), feedback from other systems higher up in the energy hierarchy (F), and the yield or contribution from the system evaluated (Y), see Figure 1. Examples of indices are percent renewable (%R) and Emergy Investment Ratio ($EIR = F/(R+N)$).



$$\text{Emergy Yield Ratio : } EYR = Y/F = (R+N+F)/F$$

$$\text{Environmental Loading Ratio: } ELR = (F+N)/R$$

$$\text{Emergy Sustainability Index: } ESI = EYR / ELR$$

Figure 1. Emergy indices (after Brown and Ulgiati 2004).

1.2. Sustainability field

Sustainability and sustainable development (in this paper they will be used as synonyms²) are important concepts in humanity's strive for long time existence, however also concepts that are debated to some extent (see e.g. Elliott, 2012). There is almost complete consensus that sustainability has three aspects: environmental, economic and social sustainability. Another important feature is the intergenerational equity aspect, expressed by the World Commission on Environment and Development (WCED, 1987) as: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". The three aspects – environmental, economic and social sustainability – is often referred to as the three pillars of sustainability or the "triple-bottom-line". Goodland (1995) depicted the three sustainability aspects with three rings, and sustainable development defined as the area where all three rings overlap. As pointed out by Giddings et al. (2002) the problem with this model is that it gives the picture of a separation between environmental, economic, and social aspects, while a probably more true model is that they are interconnected to a large extent (see e.g. Odum, 1994). A good overview of this sustainability discussion can be found in Palme (2007).

² The two concepts can be defined separately, e.g. that sustainability is the end goal and sustainable development are the many possible roads to sustainability (see e.g. Robèrt et al. 2019). However, there is no consensus, or even close to consensus, regarding this, therefore synonyms in this paper).

There are many factors to consider regarding sustainability. Crucial is our ability to assess sustainability, or assess our position in relation to the sustainability goals we want to achieve.

Many claim that the success of the sustainable development concept lies in the varied ways it can be interpreted, and that diverse and possibly incompatible interests can "sign up to" sustainable development. Elliott (2013) referred to this as "constructive ambiguity". Jacobs (1991) identified sustainable development as a "contestable concept" similar to "democracy" or "equality". It has a basic meaning that almost everyone is in favour of, but there are deep conflicts around how they should be understood and fostered.

1.3. Objectives

The objectives of the paper are:

- A comparison of the modelling approaches used in energy sustainability papers with a more general view based on a selection of sustainability textbooks
- Present conceptual energy systems models of non-overlapping areas between energy sustainability models and general sustainability field defined by a selection of sustainability textbooks.

The paper is based on literature studies and some indicative thinking.

Section 2.1 covers the use of the energy concept in the context of sustainability, first in the older perspective of HT Odum's writings, and then a more recent perspective (Grönlund, 2016).

Section 2.2 tries to capture the more general view of the sustainability concept from four commonly used textbooks in first cycle teaching (undergrad, bachelor's level).

Section 2.3 identifies the overlapping and diverting areas of section 2.1 and section 2.2.

Section 2.4 present possible conceptual energy systems diagrams addressing non-overlapping areas from section 3.3.

2. Results

2.1. Energy and sustainability

2.1.1.H.T. Odum's writings

An index search for variations of the words *sustainable* and *sustainability* (*sustainab**) reveals that the concept is not mentioned in what can be called H.T. Odum's "modeling books":

- Odum, H. T. (1983). *Systems ecology: An introduction*. New York: John Wiley & Sons.
- Odum, H. T. (1994). *Ecological and general systems - an introduction to systems ecology*. Niwot, CO, USA: Univ. Press of Colorado.
- Odum, H. T., & Odum, E. C. (2000). *Modeling for All Scales*. Harcourt Publishers Ltd.

The concepts appears, though, in Odum's three other main books:

- Odum, H. T. (1996). *Environmental accounting. Energy and environmental decision making*. New York: John Wiley & Sons.
- Odum, H. T., & Odum, E. C. (2001). *A Prosperous Way Down: Principles and Policies*. Boulder, Colorado, USA: University Press of Colorado.
- Odum, H. T. (2007). *Environment, power and society for the twenty-first century*. New York: John Wiley & Sons.

In Odum (1996:244) Odum writes under the subheading "Steady Sustainability":

"In economics, the equivalent to the ecological-climas concept for the global economy is 'sustainability'. However, the steady-state type of sustainability may not be possible because short-term advantage favors consumer that use up accumulated reserves. What is generally observed is pulsing, with small oscillations nested in time and space within larger ones." (Odum, 1996:244)

He then use a little more than one page to describe the "Pulsing Sustainability" under that subheading (figures 13.1, 13.3, and 13.4 in Odum 1996) The title of the Odum and Odum (2001) book, *A Prosperous Way Down*, refers to phase three in the pulsing sequence, see Figure 2.

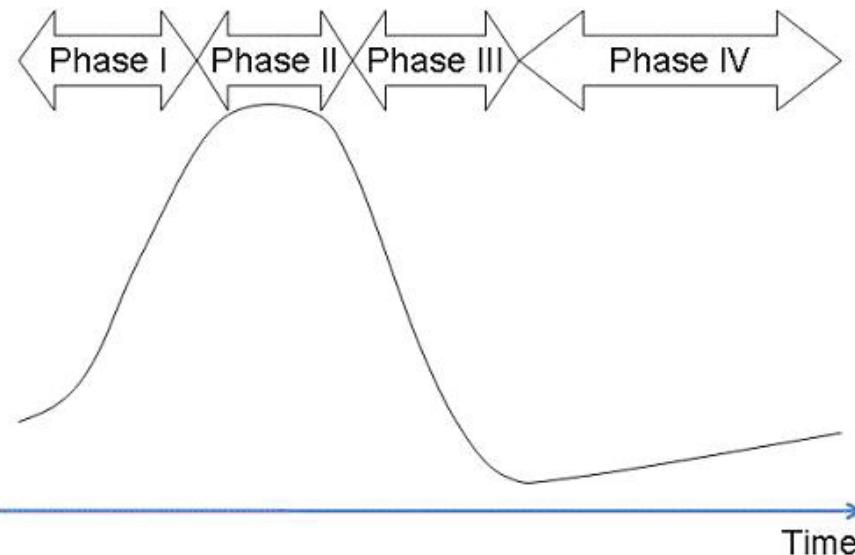


Figure 2. The four pulsing stages, when repeated constituting a long-term sustainable pattern (after Odum et al., 1995).

His last book *Environment, power and society for the twentyfirst century* use the concept "The steady state misconception" and dedicate one full chapter to *Climax and Descent* (Chapter 13 in Odum 2007).

2.1.2. Four types of use regarding sustainability

Grönlund (2016) gave an overview of how sustainability has been used in the context of the energy concept. Four types of uses were found: 1) the Energy Sustainability Index (ESI), 2) energy as a normalizing measure, 3) energy as a network measure, and 4) the pulsing paradigm.

2.1.2.1. ESI, Energy Sustainability Index

The ESI was introduced by Brown and Ulgiati (1997) and Ulgiati and Brown (1998) as "...an aggregate measure of economic (large yield) and environmental (low stress) compatibility."³ It is defined as the Energy Yield Ratio divided by the Environmental Load Ratio (Figure 1). It captures, on the yield side, the contribution of an activity (e.g. forestry or fish farms) to the larger system (e.g. society), and on the stress side the increasing load on the local system (which original state is measured by R) from released local non-renewable resources (N) and purchased resources introduced to the local system (F). The ESI measure has been frequently used by many authors, often interpreted in a far more general way than originally suggested by Brown and Ulgiati (1997). An interesting discussion regarding the ESI was

³ The Happy Planet Index (HPI) has a similar approach, rewarding a good life (estimated by perceived life satisfaction and calculated life expectancy) and low ecological footprint, see <http://happyplanetindex.org/>. However, in the ESI all factors used in the index has the same unit: sej/year.

published as Letters to the editor in the journal Ecological Modelling during 2011 and 2012 (Harizaj, 2011; Brown and Ulgiati, 2011; Giannetti (2012). The focus of the discussion was what factors would maximize the ESI. Of course high yield (EYR) and low load (ELR) will do it, but it was investigated in which constellations of R, N and F. The outcome of the discussion was that it was clear that the ESI still needs refining and that it "...does not capture the complexity of the sustainability concept" (Brown and Ulgiati, 2011).

2.1.2.2. Emergy as a normalizing measure

The probably most attracting feature of emergy accounting is its mechanism of normalizing flows to the same unit, not only between energy and matter, but also between energy and money (Odum 1996); this is almost unique among environmental assessment methods. Thus when drawing an energy diagram (according to Odum 1996 and Brown and Ulgiati 2004), it is not only possible to illustrate flows of energy, matter, information, and money within the same diagram, it is also possible to put values on all of the flows with the same unit: *sej* (solar energy joules). From a sustainability point of view it is also interesting that when using the energy hierarchy diagrams of emergy accounting the domains of the traditional triple-bottom-line approach in the sustainability debate comes out naturally (Grönlund et al. 2008), see Figure 3. In each of the three domains it is possible to use the normalized quantitative numbers of emergy regardless of the original units of the flows, be it joules, kg, bits or Euros. In practice this has been done for the ecological and economic sustainability domains⁴, but for the social sustainability domain it is still more of a hypothesis, mainly since the social sustainability parts are still problematic in the collection of raw data.

2.1.2.3. Emergy as a network measure

Since emergy is often presented in a thermodynamic (TD) context, the concept is often mistaken for being of the "state variable" measure type. We are also used to talk about flows of energy, so therefore it is easy to assume that emergy is also a flow. However, this is not so clear. Possibly emergy instead should be viewed as properties following the energy flows⁵. It is obvious that emergy accounting has something to do with the network of flows in systems. Looking into any explanation of emergy accounting (e.g. Odum, 1983, 1994) it is clear that the connections and interactions between the parts in the system is the main focus.

The energy hierarchy has been suggested as a new thermodynamic (TD) law since it claims to describe distribution and dynamics of energy in universal terms (Odum 1994). Grönlund and Brandén Klang (2009)¹² and Grönlund (2016) suggested that a problem for this hypothesis to have a breakthrough as an accepted TD law is due to the fact that it expands the classical TD (heat TD, Figure 4a). This expansion is not performed by those who work with the classical TD (mainly heat engine and chemical engineers) but by other research groups who are not used to view their work as TD (Figure 4b). These groups are for example business modellers, computer scientists, and meteorology modellers, working with theories of networks, systems, and complexity (Figure 4b). The expansion also includes new systems ecology measures with a network focus as Environ (e.g. Patten 1992, Patten and Fath 1998), Ascendancy (e.g.

⁴ See for example a collection of international journal publications at www.emergysystems.org or www.cep.ees.ufl.edu/emergy/publications/emergy.shtml

⁵ Going deeper into this hypothesis we must also separate the "real" properties following each flow from the estimation we use in the calculations according to the methodology. The "real" properties differ for each individual flow of wood, oil, or mobile phone, since they all have a different background in the history of the flows interacting to create the currently investigated flow. The estimations we use in the calculations are tabulated averages, in a similar way as LCA is performed. The energy values are also standardized values from tables, however, with a higher exactness than is possible for emergy or LCA tables.

Ulanowicz 1997) and Emergy (e.g. Odum 1994) (Figure 4b). A special case is the measure Eco-exergy (Jørgensen 2006) which takes its fundaments much more explicit in the old classical TD but address the new quality aspects⁶. Grönlund and Brandén Klang (2009)¹² suggested that also the Extended Exergy concept (Sciubba 2003) is taking this step by adding money to the classical TD.

Brian Fath points out⁷ that exergy, eco-exergy, ascendancy, and energy – despite they are developed in different contexts – mathematically have a similar approach to include the qualitative aspects: by introducing a compensation factor. The aim of this factor is to capture the information component, not covered by the traditional energy measure⁸. Grönlund (2009) pointed out that a general measure of qualitative information seems to be missing in science. In Figure 5 the three major types of flows known in the universe – energy, matter, and information – are listed. The information category is split into two: money (€, \$, or equivalent) and information (bit). In the mid part we can see how these concepts are generally used within science. Energy is measured in joules (J), whether in the form of potential, kinetic, pressure, chemical, or heat energy. Everybody knows, though, that there are specific qualitative aspects for every energy form. If you have 1 kWh (3600 kJ) of hot coffee and 1 kWh of electricity only one of those energy forms can make the electric bulb above you light up due to differences in quality aspects. Two more general concepts have been introduced to correct the energy value according to their qualitative aspects in the system: exergy and emergy. It is interesting that the view on energy by the general public (to the right in Figure 5) is the more qualitative approach, even if it is not labelled exergy or emergy (the general public labels it “energy”). When it comes to matter the situation is the opposite. Both scientists and the general public takes for granted that different materials have different qualitative properties. Only rarely, like for luggage in an aeroplane, we (almost) only care about mass, not different types of mass. The same goes for money. Only small children count the coins: 1, 2, 3, 4, 5 coins. Very soon we learn to add up different qualities (values) of different coins, even if their mass and energy content are very similar. When it comes to information, the general measure is the “bit” (8000 bits = 1 kilobyte). The bit measure is of the same type as the joule, it does not take into account different qualitative aspects of the information. You can probably count how many bits were shouted in a rain forest at night, but you have no idea of the quality of what was said. However, in everyday language the interpretation of the word “information” has a qualitative approach. But, a more general scientific measure of information quality seem to be missing. A candidate may be possible to derive from H.T. Odum’s emergy approach. In emergy accounting the joule is renamed emjoule when the network quality aspects are added. In the same way the bit can be renamed embit⁹ when the qualitative aspects captured with the emergy accounting approach is added to the information (Grönlund 2009, 2019).

⁶ Readers familiar with the eco-exergy concept know that Jørgensen use the number of genes in an organisms as an estimator for the information content added to the more classical TD based exergy accountings. Compared to the other measures Jørgensen, however, has less focus on the network and more focus on the classical TD math when presenting eco-exergy. In this context it should be mentioned that Odum, Patten and Ulanowicz also stand solid on classical TD, but don’t use it as explicitly as Jørgensen when explaining their new network TD measures.

⁷ Pers.comm., Montpellier, France, 2016, at the ECOSUMMIT conference.

⁸ Literally the information part can be viewed as “burned” away when converting different types of energy values to heat values, e.g. in a bomb calorimeter. Just moving a system out of its context to investigate it in a laboratory, destroys significant amounts of the information aspects, since the system is now “disconnected” from its context.

⁹ It is not clear to the author of this paper who coined the term “embit”. Mark T. Brown has addressed the topic in several speeches, for example at the emergy conference in Gainesville, Florida (Brown, MT. 2005. Areal Empower Density, Unit Emergy Values, and Emformation. Pages 1-15 in Brown MT, ed. *Emergy Synthesis 3: Theory and Applications of the Emergy Methodology*. Proceedings from the Third Biennial Emergy Research Conference, Gainesville, Florida, January, 2004. Gainesville, USA: The Center for Environmental Policy, University of Florida)

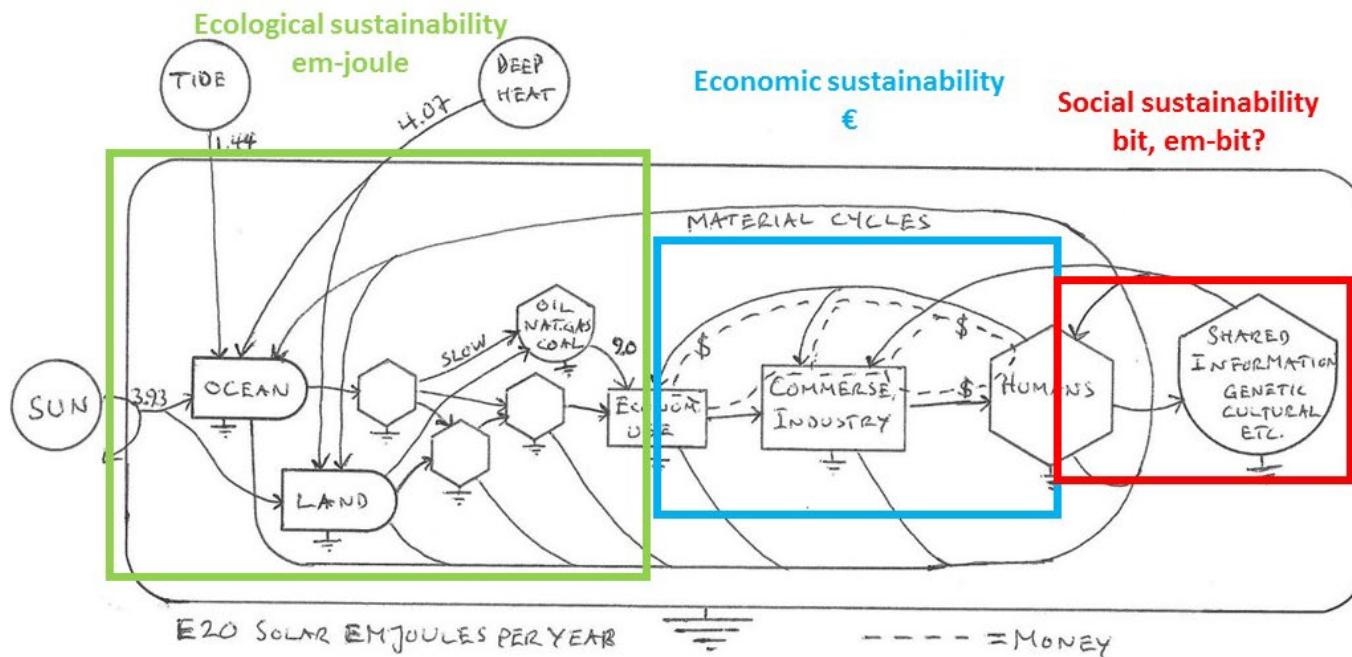


Figure 3. The triple-bottom-line domains in the energy hierarchy (modified from Odum 1996, Figure 3.1, by Grönlund et al. 2008, 2018).

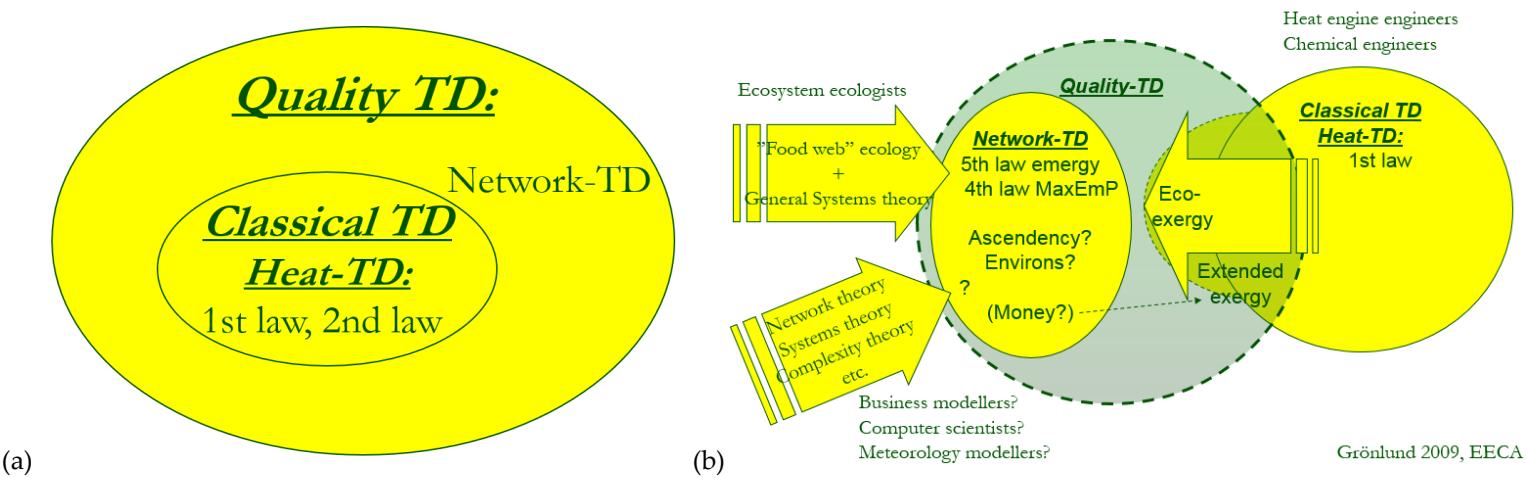


Figure 4. a) A view of the expansion of the field of thermodynamic (TD) from the classical heat TD to quality TD including network TD; b) A suggested thermodynamic classification of the new ecosystem theories emerging. (From Grönlund and Brandén Klang 2009¹² and Grönlund 2016).

¹² Grönlund E, Brandén Klang A. 2009. *The use in Ecological Engineering of New Ecosystem Theories based on New Thermodynamic Laws*. Powerpoint presentation from the conference Ecological Engineering: from concepts to application, Cité internationale universitaire de Paris, France, 2-4 December, 2009. Östersund, Sweden: Mid Sweden University.

Measures used in the scientific community		Perception of the scientific community		Perception of the general public	
Quantitative	Qualitative and quantitative	Quantitative	Qualitative and quantitative	Quantitative	Qualitative and quantitative
Energy, J	Exergy, J Emergy, seJ	Energy, J		Exergy, J Emergy, seJ	
Mass, kg	Type of atom- & molecule, kg Material, kg		Type of atom- & molecule, kg Material, kg	Type of atom- & molecule, kg Material, kg	
Money, numbers	Money, € \$		Money, € \$	Money, € \$	
Information, bit	- (missing)	Information, bit		- (missing)	

(Grönlund and Brandén Klang, 2009, EECA, Paris)

Figure 5. Scientific perception of the 4 major flow types in the universe. Money can be considered an information measure, but of a different type than the bit, so therefore they have separate status in this table. (From a presentation in Paris 2009 by Grönlund and Brandén Klang 2009¹²).

2.1.2.4. Pulsing sustainability

A wanted stable steady state is often intrinsic in definitions of sustainability. However, for example Odum et al. (1995) argue that pulsing is the normal state for systems: the pulsing paradigm. If pulsing is a general systems pattern, sustainability is likely to have different features in different stages of the pulsing cycle. Odum et al. (1995) divide the pulsing pattern into four stages: (I) growth, (II) stagnation, (III) decline, and (IV) slow regeneration (Figure 3). Odum and Odum (2001) gave different suggestions and strategies for sustainability in the different stages. In the pulsing context, during phase I it is observed a wanted outcome of continuous growth. This growth may be considered sustainable if it is part of a pulsing pattern that is sustainable as a whole. Grönlund (2020) looked at 10 sustainability related energy papers, and found that of them no one included the pulsing approach.

2.2. Sustainability paradigmatic dimensions

All four textbooks studied in this investigation (Caradonna 2014; Elliott 2012; Robèrt et al. 2019; Rogers et al. 2008) ascribe opposing paradigms in the view of sustainability or sustainable development. Two main types of such paradigmatic dimensions were identified in the textbooks:

- Strong and weak sustainability – in terms of economic capital
- Malthusians and Cornucopians – in their view on limits or no limits

One of the textbooks had an additional description of the above, called “funnel” or “cylinder” paradigms (Robèrt et al. 2019), which will be described below.

The paradigms are summarized in Figure 6.

2.2.1. Strong and weak sustainability

Strong and weak sustainability focus on different types of economic capitals. Rogers et al. (2008) use the division of Human, Man-made, and Natural Capital. In short they concluded that: 1) Weak sustainability requires that the sum of all capital be constant or increasing over time. Substitution between the different types of capital is possible. They also point out that “Most of the literature...thinks

in terms of weak sustainability..." (Rogers et al., 2008). 2) Strong sustainability on the other hand requires that all of the above capitals be increasing over time, and substitution between the different types of capital is not possible.

2.2.2. Malthusians and Cornucopians

Strong and weak sustainability are often described as related to limits or non-limits. This is not the original definition of these concepts, which is rather related to different economic capitals as described above. The discussion of limits or non-limits are closer connected to the concepts of Malthusians and Cornucopians, where the former group believes in limits of different types, and the latter see "...a future limited only by human ingenuity..." and a "...future as not resource limited, but limited by humans' inability to get the economic institutions right" (Rogers et al., 2008).

2.2.3. Funnel or cylinder paradigm

Robert et al. (2019) describe a similar paradigm situation with the metaphor of a funnel and a cylinder. The funnel give the picture of a decreasing navigation space for companies and organizations due to declining resource availability, and restoration capacity (regenerative capacity), and increasing pressure from population, average resource demand, market competition, regulations etc. Only those companies and organizations that can navigate towards the thought opening of the funnel will survive in the competition and be considered sustainable. In connection to this picture, they present systems conditions that can work as a navigator to steer towards the opening of the funnel. The cylinder paradigm on the other hand do not show any declining resource availability, and restoration capacity. Human actions affect resource availability and restoration capacity, but not to an extent that they are decreasing. The cylinder paradigm is acknowledging that there are limits, but humanity's actions are still far from these limits.

The funnel and cylinder paradigm picture resemble very much Herman Daly's picture of a "full world or an empty world, where in the empty world there are still a lot of resources and assimilation capacity compared to the human economy, but in the full world the opposite situation exists: the human economy is filling up the world to an extent that resource and assimilation capacity is becoming scarce.

2.3. Gap between emergi-sustainability and textbook-sustainability

Comparing section 2.1 with section 2.2. gives that the following gaps exist in the energy description of sustainability compared to the textbook approach in section 2.2:

- Strong and weak sustainability are not addressed.
- A cornucopian view is not addressed.
- A cylinder view is not addressed.

2.4. Suggested energy modelling approaches for non-covered textbook sustainability approaches

Based on the gaps in section 2.3, some suggested conceptual energy models are presented below as a beginning of filling these gaps.

2.4.1. Weak and strong sustainability

In Figure 7a a typical energy system setup is presented. Figures 7b and 7c show the substitution process of weak sustainability, where natural capital is exchanged for financial capital.

Approximately parallel scales but in different spaces (dimensions)

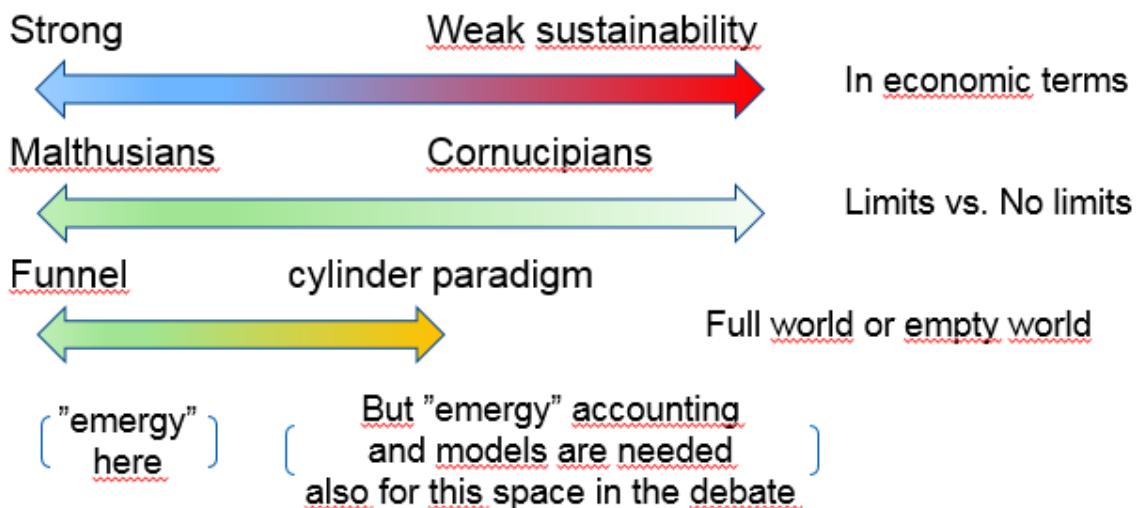


Figure 6. A summary of the sustainability paradigms found in the four textbooks studied in this investigation (Caradonna 2014; Elliott 2012; Robèrt et al. 2019; Rogers et al. 2008) with the main opposing paradigms in the view of sustainability or sustainable development. Strong and weak sustainability in terms of economic capital, Malthusian and Cornucopian view related to the view on limits versus no limits, and the additional description in Robèrt et al. 2019, called "funnel" or "cylinder" paradigms, where the cylinder paradigm acknowledges limits but claim that human actions so far are still far away from these limits.

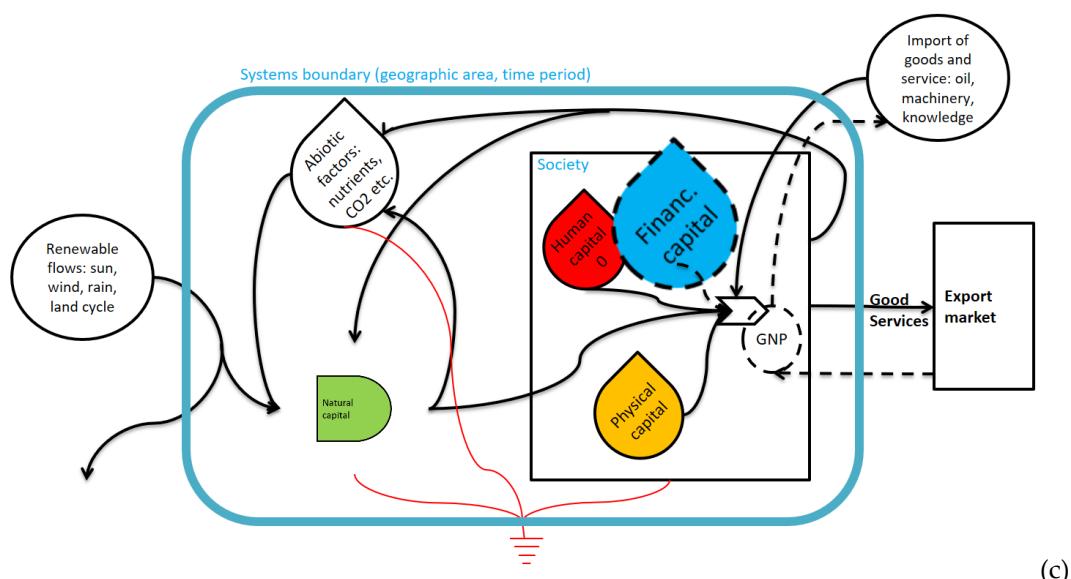
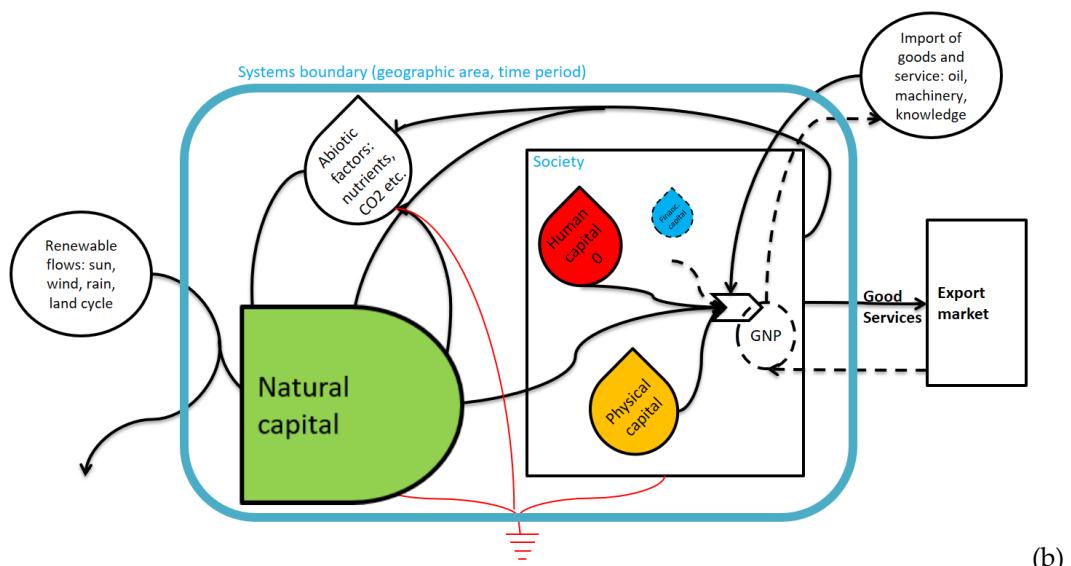
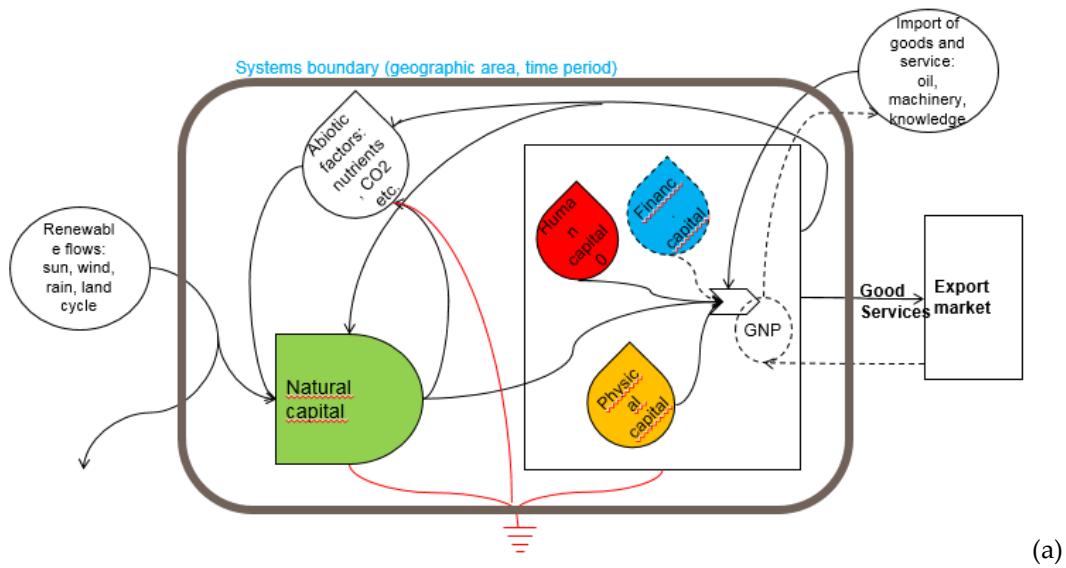


Figure 7. A hypothetical Weak sustainability substitution where capital can be substituted by each other, in energy diagram language. a) a traditional generic energy diagram; b) financial capital is substituted for natural capital; c) natural capital is substituted for financial capital.

In Fig. 7, a theoretical depiction of energy is displayed, where the energy hierarchy, usually depicted from left to right, instead be depicted vertically. Transformity is then a measure of the height of the energy hierarchy, and energy is the width of the basis in the hierarchy. It should be pointed out that energy hierarchies never look like this in reality, since this picture don't include any storages that release or store resources between years. Fig. 7b shows an assumed outcome of the substitution in 6c, where natural capital has been substituted by financial capital. Since financial capital can be found higher up in the energy hierarchy, it is assumed that the height of the energy hierarchy must increase, while the basis will decrease.

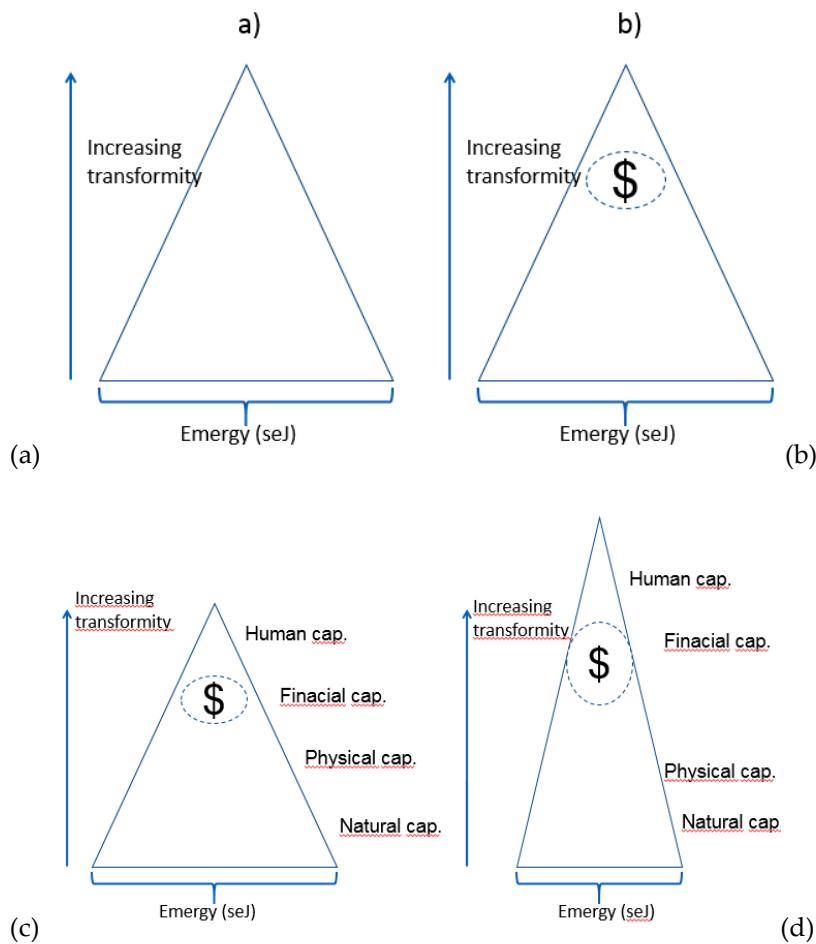


Figure 8. **a)** A simplified energy hierarchy (with no storage interference), where transformity is a measure of how high up in the energy hierarchy an item or phenomenon occurs, and the basis of the hierarchy (triangle) represents the energy measure expressed in one type of energy, normally solar equivalent joules (seJ); **b)** representing monetary circulation at a certain level in the energy hierarchy; **c)** hypothetical distribution of human, financial, physical, and natural capital in relation to levels in the energy hierarchy; **d)** hypothetical weak sustainability substitution of natural capital (low in the energy hierarchy) for financial capital (higher up in the energy hierarchy), similar to the depiction in figure 7c.

2.4.2. Malthusians vs. Cornucopians

As seen in the gap analysis in section 2.3 the Malthusian view is well covered in energy literature, but not the Cornucopian view. Since the Cornucopian view depend on ingenuity, it is per definition “not known” yet. It can, though, be included as a modelled part, like were done by the Limits to Growth approach in the 1970s (Meadows et al. 1972, 2002). Figure 9 show an example how ingenuity can be included from the perspective of ingenuity affecting renewable and feedback inflows, ingenuity of efficiency within the existing sources, and not yet discovered sources.

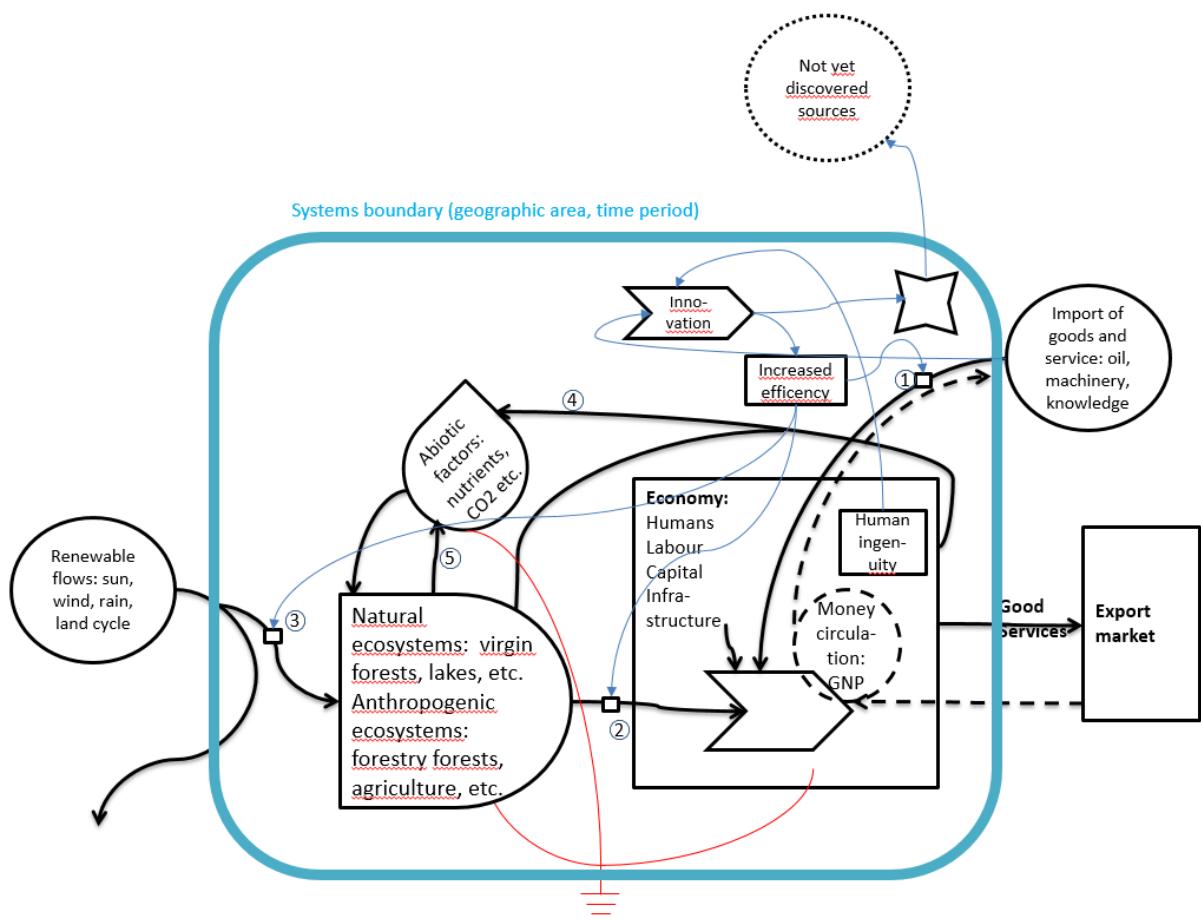


Figure 9. Human ingenuity added to the economy, driving innovation and increased efficiency, which interacts with (1) imported goods and services to increase efficiency in imported goods and services, (2) goods and services from natural and anthropogenic ecosystems, (3) the capture of the renewable flows. (4) and (5) indicates that also the abiotic factors can be addressed by innovation: mineralization flows, releasing and regenerating nutrients, and other abiotic ecological factors as temperature, light etc. The switch symbol in the upper right of the figure depicts innovation that leads to new discovered sources.

2.4.3. Funnel vs. cylinder paradigm

The difference between the funnel or cylinder paradigm will not be visible directly in a traditional systems diagram. In a time diagram of nonrenewable resources the difference will appear though, see Fig. 10. According to the funnel paradigm, non-renewable flows will decrease over time, and maybe also renewable flows will show a decreasing trend, Figure 10, upper left diagram. According to the cylinder paradigm non-renewable flows will not decrease and renewable flows will be stable, Figure 10, upper right diagram.

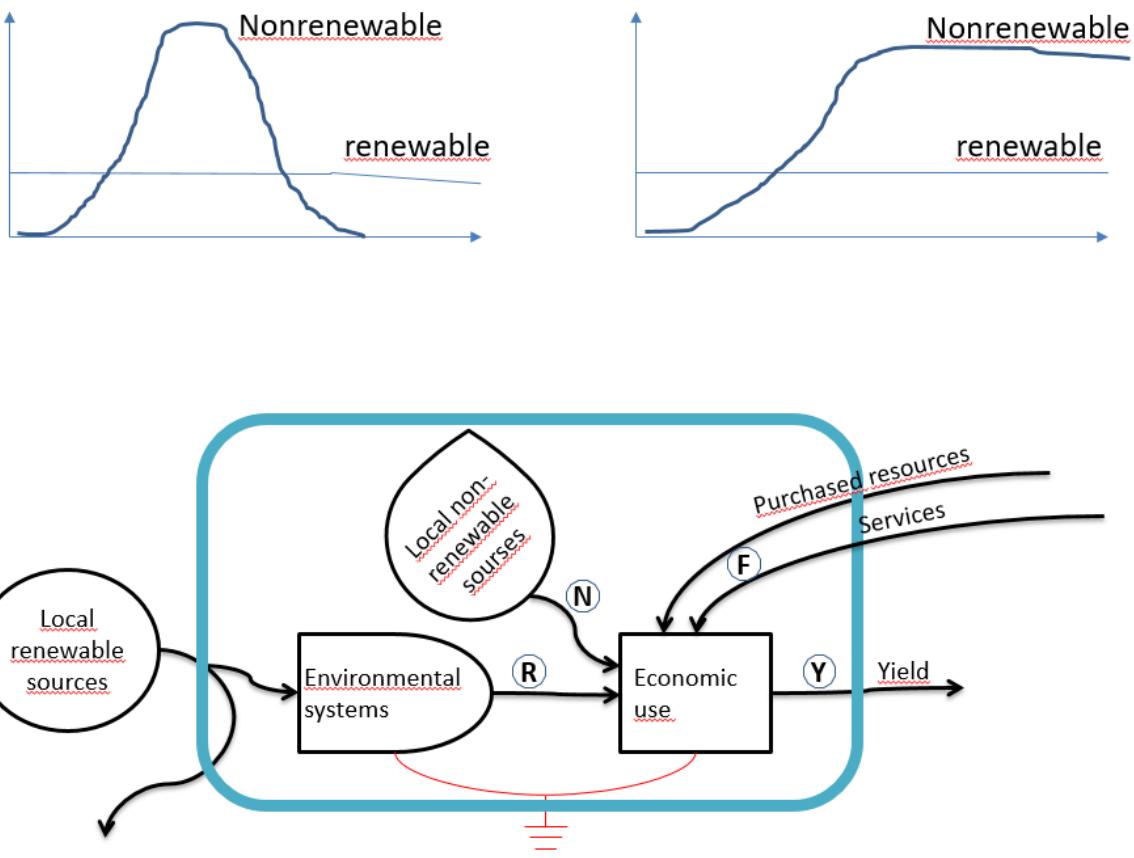


Figure 10. Principal non-renewable (N) and renewable (R) flows with diagrams over time for the funnel paradigm (upper left diagram), and the cylinder paradigm (upper right diagram).

3. Discussion

Sustainability and sustainable development are still not yet fully defined concepts. The view on sustainability from emergy analysis is not crystal clear either. Most promising may be the network track, which, though, need further development in the interpretation part.

The choice of textbooks included in this paper can of course suffer from some bias, as well as the extraction of sustainability dimensions made in this paper. Important aspects from the textbooks not addressed in this paper are for example the concept of "triple-bottom-line" and the very common Venn diagram of interlocking circles, often launched under the heading People-Planet-Profit, or People-

Planet-Prosperity. Emergy accountings for different outcomes of Venn diagrams would be an interesting development of this paper. Another interesting further development would be an attempt to quantify the "ingenouity" and innovation needed for a weak sustainability approach.

H.T. Odum did not use the concepts of sustainability or sustainable development in his writings to any larger extent. When he did it, the focus was on the pulsing pattern, and especially the downslope of the pulse, among energy researchers and debaters summed up under the concept of "a prosperous way down". However, it must be remembered that Emergy accounting is a method, not a standpoint. Energy accounting must therefore not be stuck in the "prosperous way down" narrative, even though the many mini-model calculations and "peak-oil" assumptions talks in its favor of a pulsing behavior and a "prosperous way down" narrative.

Regarding the "triple-bottom-line", there are in the literature many interesting energy investigations published regarding the environmental/ecological aspect. The other two pillars of the "triple-bottom-line" have not been investigated to the same extent with energy accounting. More of deeper, quantitative investigations regarding economic sustainability or social sustainability would be an interesting development of the energy accounting field. It must be remembered that most of the Odum statements regarding the socio-economic parts of the "prosperous way down" narrative are very, very interesting hypothesis, but not yet backed up by solid energy accountings. Is there a risk of a Garrett Hardin versus Elinor Ostrom outcome? Where Garrett Harding produced very interesting models based on game theory, but Elinor Ostrom could not find that his modeling outcome where very common in real case studies.

In general a possible standpoint from this paper is to recommend the field of energy accounting to connect more also to other sustainability narratives. And to have less focus on showing them wrong, instead of investigating what would be needed in the models to make them possible. Again, Energy accounting is a method, not a standpoint. The results from quantitative accounting investigations can lead to a standpoint, but not easily prove that other standpoints are definitely wrong within the still a little bit shaky field of sustainability.

4. Conclusions

This paper compared, from a modelling perspective, different sustainability approaches covered by Energy analysis, with more general views on sustainability and sustainable development based on a selection of sustainability textbooks. For the areas not yet covered by energy analysis, conceptual model approaches were suggested.

The four different approaches of assessing sustainability identified were: 1) the Energy Sustainability Index (ESI), 2) energy as a normalizing measure, 3) energy as a network measure, and 4) the pulsing paradigm. The general aspects from textbooks were presented as three pairs of paradigm views on sustainability: 1) Strong and weak sustainability, 2) Malthusian vs. Cornucopian view, and 3) the "funnel" vs. "cylinder" sustainability paradigm. It was found that the strong sustainability, the Malthusian view, and the "funnel" paradigm were already to a significant extent covered by the existing energy approaches. The new suggested conceptual models included capital substitution for weak sustainability, ingenuity and innovation for the Cornucopian view, and the choice of presentation to clarify the view for the "funnel" vs. "cylinder" paradigm.

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Energy on different scales: the case study Norderön – Jämtland – Sweden

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An important feature in energy evaluations, in fact a key part, is the treatment of different hierarchical levels. Any energy investigation almost always relate to the national level, in order to have an appropriate energy per money ratio to use in the local or regional evaluation. If a regional energy to money ratio is available that one can be used instead, but this is rarely the case. All investigations also relate to the planetary baseline of the biosphere. The biosphere is the only hierarchical level where the ecosystem boundary forms an almost closed system to matter. Only solar energy and lunar gravity energy passes the systems border in significant amounts. However, even if relating different hierarchical levels is normal business in energy accounting, it has not been common to more in depth analyze the relationships between hierarchical levels.

With the purpose to investigate the hierarchical relationships more in depth, a case study is being formed with three hierarchical levels:

1. Norderön - a small island in Lake Storsjön with approximately 140 inhabitants on 773 ha (Figure 1).
2. Jämtland county - a region in the middle of Sweden
3. Sweden.

Based on traditional energy evaluations for these three levels, the case study will try to more in depth describe the interrelationships between the levels, and find appropriate indicators and frameworks that will best capture the hierarchical interdependencies (Figure 2). The next hierarchical level to include is likely to be the European Union, and thereafter the biosphere. This is however out of the scope for this first investigation.



Figure 1. Norderön, a small island in Lake Storsjön, which is located in the middle of Jämtland County, a county in the middle of Sweden. Maps published under Creative commons licence.

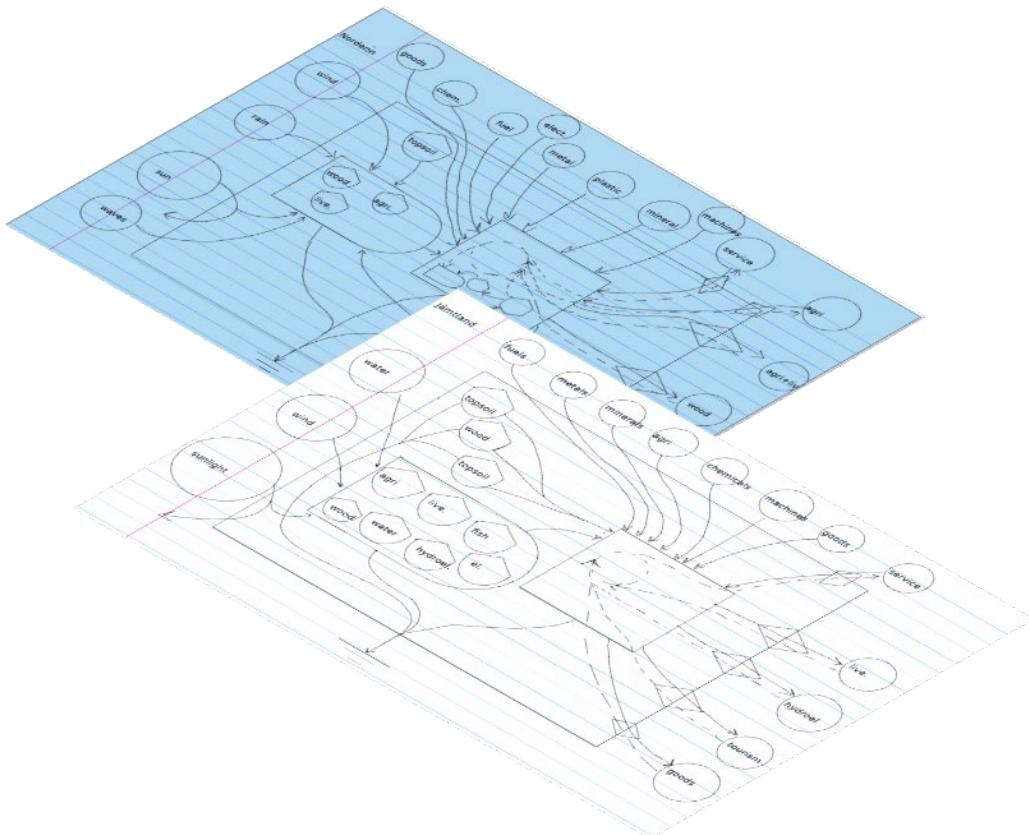


Figure 2. Preliminary system diagrams for Norderön and Jämtland County. Diagrams by Daniel Hedin.

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Oväntat olika värden på energi jämfört med energi från månen och jordens inre

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De tre energikällorna som driver biosfären

Solljus är den klart största energikällan för biosfären. $5,61 \text{ E}+24$ joule per år ($\text{E}+24 = 10^{24}$) flödar varje år in till den övre atmosfären, och om vi antar att ca 30% reflekteras bort direkt, så innebär det att nettoenergin som absorberas av planeten Jorden är $3.93 \text{ E}+24$ joule per år [1].

Energi når också Jorden i form av gravitationsenergi från månen; vi upplever det som tidvatten. Den energimängden är dock väldigt liten jämfört med solinstrålningen: ca $5,2 \text{ E}+19 \text{ J/yr}$ [2] vilket bara är 0,001% av den inkommande solstrålningen.

Den tredje oberoende energikällan till biosfären kommer från jordens inre, djupvärme (deep heat). Enligt Sclater et al. [3] kommer ca $1,98 \text{ E}+20 \text{ J/år}$ från radioaktivt sönderfall i jordskorpan, och ca $4,74 \text{ E}+20 \text{ J/år}$ från värmeflöden från manteln i jordens inre. Det blir total $6,72 \text{ E}+20 \text{ J/år}$, vilket är bara 0,017% jämfört med solinstrålningen.

Omräkning till emergivärden ger oväntade proportioner

När vi räknar om dessa tre oberoende energikällor till energiflöden ändras proportionerna mellan flöden oväntat mycket. Emergivärdet för solenergin har samma värde, $3,93 \text{ E}+24 \text{ sej/år}$, men emergivärdet för tidvatten-energin från månen har beräknats till så mycket som $3,83 \text{ E}+24 \text{ sej/år}$, och djupvärmens till ännu mera: $8,06 \text{ E}+24 \text{ sej/år}$.

Från att ha varit bråkdelar av procent av energi-inflödet så är månens och djupvärmens inflöde i emergitermer av samma storleksordning som solinstrålningen. Detta kan verka förvånande, och till och med vara en felräkning, men flera olika beräkningar har under en period av 30 år givit liknande värden. Om värdena stämmer kan det ge oss anledning att övervädra hur vi ser på biosfärens energiförsörjning. Energivärdena i joule per år är sannolikt riktiga, men emergivärden försöker inkludera kvalitetsaspekter hos energiflödena, och säger sannolikt något om det inflytande dessa flöden har på jordens ekosystem.

Den oväntade skillnaden i värden spelar ingen roll för emergiberäkningarna

Lyckligtvis visar det sig att de oväntade proportionerna i emergitermer mellan energislagen inte har någon betydelse för emergiberäkningarna. Det beror på att i emergiberäkningar används summan av dessa tre oberoende energikällor, $9,44 \text{ E}+24 \text{ sej/år}$, som en baslinje för alla andra beräkningar. Flera olika baslinjer har använts de senaste 40 åren, och när en hämtar värden (oftast transformiter) från olika undersökningar korrigeras värdena enkelt genom en proportionalitets-faktor. Om en emergianalytiker/-syntetiker misstror värdena för månen och djupvärmens, kan dessa enkelt dras bort och alla värden korrigeras med proportionalitets-faktorerna. Resultaten i analysen blir alltså ändå proportionerligt desamma.

Emergianalysen är inte ensam om att använda en baslinje för beräkningar på detta sätt. Ekologiska fotavtryck är en annan metod som använder baslinje [4]. Idag används baslinjen 11,9 gha (global hectars), men tidigare har andra baslinjer använts, t.ex. 51 gha och 11,2 gha. Samma gäller där, att de är proportionella.

Att jämföra resultat som beräknats med olika baslinjer är alltså inte rimligt, men det är som sagt relativt lätt att korrigera så jämförelsen blir rättvis (även ekonomiska metoder använder korrigeringar som inflationskorrigrade pengavärden).

Den mest använda baslinjen i emergisammanhang är 9,44 E+24 ej/år [6], men även 15,83 E+24 ej/år användes under en period. [1].

2010 uppdaterade Brown and Ulgiati [5] baslinjen till 15,2 E+24 ej/yr och 2016 revideras den till 12,1 E+24 ej/år [7] och 12,0 E+24 ej/år.

Vad talar för att emergibilden är mer riktig än energibilden?

Intressant blir naturligtvis att försöka förhålla sig till emergiberäkningarnas värden. När det gäller månens tid-kraft, är det uppenbart att för ekosystem i tidvattenzoner har tidvattnet större inflytande än de bråkdels procent som energivärden ger.

När det gäller djupvärmen kan det vara så att vår vardagserfarenhet är begränsad. Hur mycket av värmen några meter ned i jorden är lagrad solinstrålning, och hur mycket kommer från djupvärmen? Kanske är det ett argument för emergivärdena att bergvärme och jordvärme faktiskt kan konkurrera i pris på marknaden med solvärme?

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Emergipublicationer med anknytning till Skandinavien 1994-2019

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1.	Emergipublicationer med anknytning till Danmark.....	59
2.	Doktorsavhandlingar Sverige	61
3.	Licentiatavhandlingar Sverige.....	61
4.	Emergipublicationer med data från Sverige.....	62
i.	Vetenskapliga artiklar och rapporter (kronologisk ordning)	62
ii.	Konferenspublicationer (kronologisk ordning)	63
iii.	Master- och kandidatuppsatser (kronologisk ordning)	63
iv.	Populärvetenskapliga publicerationer (kronologisk ordning).....	64
5.	Emergipublicationer av svenska forskare utan data från Sverige	64
i.	Vetenskapliga artiklar och rapporter (kronologisk ordning)	64
ii.	Konferenspublicationer (kronologisk ordning)	65
iii.	Master- och kandidatuppsatser (kronologisk ordning)	66

1. Emergipublicationer med anknytning till Danmark

(kronologisk ordning)

S. Ulgiati, C. Cialani. 2005. Environmental and thermodynamic indicators in support of fair and sustainable policy making. Investigating equitable trade among Latvia, Denmark and Italy. Pages 101–124 in W. Leal Filhos, A. Ubelis (Eds.), *Baltic Sea Region Sharing Knowledge Internally, Across Europe and Worldwide*. Series on Environmental Education, Communication and Sustainability, vol. 23, Peter Lang Publisher, Frankfurt am Main, Germany

Rydberg T, Haden AC. 2006. Energy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. *Agriculture, Ecosystems & Environment* 117(2-3):145-158

Coppola F, Bastianoni S, Østergård H. 2009. Sustainability of bioethanol production from wheat with recycled residues as evaluated by Energy assessment. *Biomass and Bioenergy* 33(11):1626-1642

Ulgiati S, Ascione M, Zucaro A, Campanella L. 2011. Energy-based complexity measures in natural and social systems. *Ecological Indicators* 11:1185-1190

Østergård H, Markussen MV. 2011. Energy Self-sufficiency from an Energy Perspective Exemplified by a Model System of a Danish Farm Cooperative, in *Energy Synthesis 6, Theory and Application of the Energy Methodology*, eds M. T. Brown and S. Sweeney (Gainesville, FL: The Center for Environmental Policy, Department of Environmental Engineering Sciences, University of Florida), 311–322.

Ghaley, BB & Porter, JR 2013, Energy synthesis of a combined food and energy production system compared to a conventional wheat (*Triticum aestivum*) production system. *Ecological Indicators* 24:534-542.

- Kamp A, Østergård H. 2013. How to manage co-product inputs in emergy accounting exemplified by willow production for bioenergy. *Ecological Modelling* 253:70-78
- Markussen MV, Kulak M, Smith LG, Nemecek T, Østergård H. 2014. Evaluating the Sustainability of a Small-Scale Low-Input Organic Vegetable Supply System in the United Kingdom. *Sustainability* 6(4), 1913-1945
- Seghetta M, Østergård H, Bastianoni S. 2014. Energy analysis of using macroalgae from eutrophic waters as a bioethanol feedstock. *Ecological Modelling* 288:25-37
- Wright C, Østergård H. 2015. Scales of renewability exemplified by a case study of three Danish pig production systems. *Ecological Modelling* 315:28-36
- Kamp A, Morandi F, Østergård H. 2016. Development of concepts for human labour accounting in Emergy Assessment and other Environmental Sustainability Assessment methods. *Ecological Indicators* 60: 884-892
- Kamp A, Østergård H. 2016. A Systematic Approach to Explorative Scenario Analysis in Emergy Assessment with Emphasis on Resilience. *Biophysical Economics and Resource Quality* 1(1):1-11
- Kamp A, Østergård H. 2016. Environmental sustainability assessment of fruit cultivation and processing using fruit and cocoa residues for bioenergy and compost. Case study from Ghana. *Journal of Cleaner Production* 129, 329-340
- Kamp A, Østergård H, Bolwig S. 2016. Environmental assessment of integrated food and cooking fuel production for a Village in Ghana. *Sustainability* 8(5): 404
- Morandi F, Perrin A, Østergård H. 2016. Miscanthus as energy crop: Environmental assessment of a miscanthus biomass production case study in France. *Journal of Cleaner Production* 137:313-321
- Wright C, Østergård H. 2016. Renewability and emergy footprint at different spatial scales for innovative food systems in Europe. *Ecological Indicators* 62:220-227
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2. Doktorsavhandlingar Sverige

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- Lagerberg C. 1999. *Energy analysis of the resource use in greenhouse crop production and of the resource basis of the Swedish economy*. Doctoral thesis, Acta Universitatis agriculturae Sueciae, Agraria 191, Department of Horticulture, Swedish University of Agricultural Sciences, Alnarp, Sweden.
- Björklund J. 2000. *Energy analysis to assess ecological sustainability. Strengths and weaknesses*. Doctoral thesis, Acta Universitatis agriculturae Sueciae, Agraria 242, Department of Ecology and Crop Production Science, Swedish University of Agricultural Sciences, Uppsala, Sweden.
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4. Emergipublicationer med data från Sverige

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- Björklund J, Johansson B. 2012. Assessing multifunctionality in relation to resource use: a holistic approach to measure efficiency, developed by participatory research. Pages 161-173 in Marta-Costa, A. A. & Soares da Silva (eds.): *Methods and procedures for building sustainable farming systems*. E. L. D. G.; Springer, Dordrecht, Netherlands.
- Rydberg T. 2012. Land is a prerequisite for food production. Pages 16-18 in Christine Jakobsson (ed): *Ecosystem health and sustainable agriculture 1*, Baltic University Press, Uppsala.
- Russo, T., Buonocore, E., & Franzese, P. P. (2014). The Urban Metabolism of the City of Uppsala (Sweden). *Journal of Environmental Accounting and Management*, **2**(1), 1-12.

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- In Brown, M.T. 2001 (ed). *Emergy Synthesis 1: Theory and Applications of the Emergy Methodology*. Proceedings of the 1st Biennial Emergy Conference. Center for Environmental Policy, University of Florida, Gainesville. 319 pages.
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- Brandt-Williams SL, Lagerberg Fogelberg C. Nested Comparative Emergy Assessments Using Milk Production as a Case Study
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 - Rydberg T, Cavalett O, Friman E, Gallardo G. Energy Systems Diagramming and Discourse Analysis - the Case of Large-Scale Biofuel Production
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iii. Master- och kandidatuppsatser (kronologisk ordning)

- Kindberg, Anna. 2007. *Emergy evaluation of a Swedish nuclear power plant*. Uppsala : Uppsala University.
- Carstensen, Anna-Maria. 2009. *A method for energy analysis using electricity as basis of evaluation: applied to a Swedish nuclear power plant*. UPTEC ES 09022, Självständigt arbete på avancerad nivå (yrkesexamen), 20 poäng / 30 hp, Institutionen för fysik och astronomi, Uppsala University, Uppsala.

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Kilander, Sara. 2017. *Emergianalys av ett Gotländskt jordbruk: En fallstudie av ekobonden Gunnar Bolins produktioner av betor och spannmål*. TRITA IM-KAND 2017:36, Självständigt arbete på grundnivå (kandidatexamen), 15 hp, Inst. f. Hållbar utveckling, miljövetenskap och teknik, Skolan för arkitektur och samhällsbyggnad (ABE), KTH, Stockholm.

iv. Populärvetenskapliga publikationer (kronologisk ordning)

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Fakta Jordbruk. SLU. Nr 8.

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5. Emergipublikationer av svenska forskare utan data från Sverige

i. Vetenskapliga artiklar och rapporter (kronologisk ordning)

Lefroy E, Rydberg T. 2003. Energy evaluation of three cropping systems in southwestern Australia. *Ecological Modelling* **161**(3): 195-211.

Cuadra M, Rydberg T. 2006. Energy evaluation on the production, processing and export of coffee in Nicaragua. *Ecological Modelling* **196**(3-4): 421-433.

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- Lagerberg C. 2001. Using the Best of the Best – Some Thoughts on the Integration of Environmental Assessment Tools

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- Doherty S, Rydberg T, Björklund J. Comparison of environmental assessment tools using a living systems framework

In Brown, M.T.E. Bardi, D.E. Campbell, V. Comar, S. Huang, T. Rydberg, D. Tilley and S. Ulgiati (eds). 2005. *Energy Synthesis 3: Theory and Applications of the Energy Methodology*. Proceedings of the 3rd Biennial Energy Conference. Center for Environmental Policy, University of Florida, Gainesville. 652 pages.

- Grönlund E. Why Is Energy So Difficult to Explain to My Environmental Science Friends?
- Grönlund E, Hedin D, Eriksson P-O. Is Energy Best Suited for Ecological Economics, Environmental Economics, or with an Economic Context of Its Own?
- Grönlund E, Salomonsson M. Ecosystem Services in Relation to the Local Renewable Energy Sources - Experiences from a Case Study in Northern Sweden
- Mangoyana RB, Grönlund E. Sustainable Growth: Dominating Debate and an Energy View
- Rydberg T, Cuadra M. It's About Getting Value for Your Money - But How Fair Are the Resource Flows?

Garde S, Hullin CM, Chen R, Schuler T. 2007. Towards Sustainability of Health Information Systems: How Can We Define, Measure and Achieve it? Pages 1179-1183 in Kuhn, KA; Warren, JR; Leong, TY (eds.): MEDINFO 2007: Proceedings of the 12th World Congress on Health (Medical) Informatics, Brisbane, Australia, Aug. 20-24, 2007. IOS Press.

Alarcón, C. Bergquist, D. Bjureby, E. Friman, E. Gallardo, G. Hajdu, F. Jacobson, K. Johansson, S., Lagerberg Fogelberg, C. & Rydberg, T. 2008. Understanding global patterns of production and consumption: prospects of an interdisciplinary approach. Frostell, B. Danielsson, Å. Hagberg, L. Linnér, B.-O. & Lisberg Jensen, E. (eds.). *Science for Sustainable Development - The Social Challenge with emphasis on conditions for change. Proceedings of the 2nd VHU Conference*, Linköping 6-7 sept 2007, 15-21.

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- the 5th Biennial Energy Conference. Center for Environmental Policy, University of Florida, Gainesville. 612 pages.
- Bergquist D, Rydberg T. Towards a Transdisciplinary Understanding of Energy Accumulation
- Bergquist DA. 2009. Sustainable Urban Life Beyond Peak Oil. In: *Key elements for a sustainable world: energy, water and climate change*. 2nd international workshop, Advances in cleaner production, May 20th-22nd, 2009, Sao Paulo, Brazil.
- Hellstrand S, Skånberg K, Drake R. 2009. The Relevance of Ecological and Economic Policies for Sustainable Development. *Environment, Development and Sustainability* 11 (4):853-870.
- In Brown, M.T., S. Sweeney, D.E. Campbell, S. Huang, E. Ortega, T. Rydberg, D. Tilley and S. Ulgiati (eds). 2011. *Energy Synthesis 6: Theory and Applications of the Energy Methodology*. Proceedings of the 6th Biennial Energy Conference. Center for Environmental Policy, University of Florida, Gainesville. 610 pages.
- Bergquist DA. Energy Synthesis of Urban Agriculture in Rio de Janeiro, Brazil
 - Lagerberg Fogelberg C, Bergquist DA. Small-Scale Community Based Management of Marine Resources vs. Large-Scale Industrial Aquaculture in Chile
 - Bergquist DA, Ingwersen W, King Liebenow D. Energy in Labor - Approaches for Evaluating Knowledge
- BIWAES 2015. *Energy and Urban Systems, Proceedings of the 9th Biennial International Workshop Advances in Energy Studies* (BIWAES), Stockholm 4-7 May 2015, (ed. O Kordas, S Ulgiati). Verlag der Technischen Universität Graz, Graz.
- Grönlund E, Fröling M, Skytt T. Energy, emergy and the city.
- In Brown, M.T., S. Sweeney, D.E. Campbell, S. Huang, T. Rydberg, and S. Ulgiati (eds). 2017. *Energy Synthesis 9: Theory and Applications of the Energy Methodology*. Proceedings of the 9th Biennial Energy Conference. Center for Environmental Policy, University of Florida, Gainesville.
- Rydberg T, Bergquist D, Berg PG, Hedfors, P. Energy Applications in Urban Planning and Regenerative Systems Landscape Design.
- Emergency Scandinavia 2019 – Assessing both Nature and Society. Proceedings from the 1st Scandinavian Emergency Symposium, 28 March, 2019, Mid Sweden University, Östersund, Sweden, (ed. E Grönlund).* Department of Ecotechnology and Sustainable Building Engineering, Mid Sweden University, Östersund, Sweden.
- Rydberg T. Emergiterminologi på svenska.
 - Grönlund E. Emergipublicationer med anknytning till Skandinavien 1994-2018.
 - Johansson S, Rydberg T. Är biobränslen ett hållbart alternativ? – Metodvalets konsekvenser.
 - Grönlund E. Why is energy so difficult to explain to my environmental science friends?
 - Grönlund E. van den Brink P. Emergi som kompletterande indikator till CLD-modellering av miljömålen i fjällandskapet.
 - Grönlund E. Emergi och miljömål.
 - Paschali E. Data problems in assessing country energy flows – the examples of Cyprus and Sweden.
 - Grönlund E. Handelsutbyte – emergi inkluderar ekosystemtjänsterna?

iii. Master- och kandidatuppsatser (kronologisk ordning)

Maassen, Jacinda. 2017. *Energy of an Urban Food Production System: a Case Study of Urban Agriculture in Detroit, Michigan*. Självständigt arbete på avancerad nivå (masterexamen), 30 hp. Dept. Of Earth Sciences, 2017/35, Uppsala University

ENERGY SCANDINAVIA 2020

– ENVIRONMENTAL ACCOUNTING

21 February 09:00-15:00

Q221

Energy and energy analysis/synthesis is a concept and method with high potential as a system analytical tool as useful as LCA, energy systems analysis, exergy analysis, ecological footprints, and similar methods.

Still, energy has not yet become a widespread method in Sweden. With purpose to see if energy can find more applications and increased use in Sweden and Scandinavia, a yearly symposium is launched with focus on use of the energy concept and method.

When: Friday 21 February 2020, 09:00-15:00.

Where: Mid Sweden University, campus Östersund or via the web (contact erik.gronlund@miun.se for the Zoom web link).

Cost: No cost!

Language: Mainly English, but maybe also some Swedish, Danish

Program:

09:00 Welcome to Energy Scandinavia

2020. Erik Grönlund

09:05 Short presentation round of participants.

09:20 Energy basics: the energy hierarchy,

and maximum empower – suggested 4th and 5th laws of Thermodynamics. Torbjörn Rydberg

10:20 Paus

10:40 Energy synthesis of a "green" Urban District in Uppsala, Sweden. Daniel Bergqvist SLU

11:10 Energy and money – real wealth. Torbjörn Rydberg

11:35 An analysis of the Energy-related concepts Energy, Exergy and Embodied Energy and in what way they reflect environmental load. Torbjörn Skjell

12-13 Lunch.

13:00 Energy – providing the basis for a more equal world? Anja Eliasson

13:15 Environmental accounting. Erik Grönlund

13:35 Energy view on sustainability compared to some environmental science textbook views on sustainability. Erik Grönlund

14:00 Paus

14:10 Presentation of two Master by Research positions at Mid Sweden University. Erik Grönlund

14:15 Summary discussion: questions emerging from previous presentations, and strategies for future energy research, symposia themes for coming years. Torbjörn Rydberg, Erik Grönlund

14:55 Final remarks.

15:00 End

