Economics of Macroalgae Utilization

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Numerous recent studies on macroalgae potential


J Appl Phycol
DOI 10.1007/s10811-016-0843-3

Biorefinery of the green seaweed *Ulva lactuca* to produce animal feed, chemic

Aquaculture Research

Aquaculture Research, 2016, 47, 698–707 doi:10.1111/are.12529

Production and ec *Macrocystis pyrife* the south of Chile

Tomás Correa, Alfonso Gutiérrez Cristian Bucarey

Bioenerg. Res. (2015) 8:1046–1056
DOI 10.1007/s12155-015-9594-1

An Investigation on the as a Potential Feedstock

N. V. S. N. Murthy Konda · Seema Singh Blake A. Simmons · Daniel Klein-Marcus

Published online: 6 March 2015

Renewable and Sustainable Energy Reviews

Macroalgae for biofuels production

Huihui Chen, Dong Zhou, Gang Luo*, Shiche


Algal Research

Macroalgae (seaweed) for liquid tra is next?

Rui Jiang, Kapilkumar Nivrutti Ingle, Alexand

J Appl Phycol
DOI 10.1007/s10811-016-0843-3

Biorefinery of the green seaweed *Ulva lactuca* to produce animal feed, chemicals and biofuels

Paul Bikker[1] · Marinus M. van Krimpen[1] · Piet van Wikselaar[1] · Bwee Houweling-Tan[2] · Nazareno Scaccia[2] · Jaap W. van Hal[3] · Wouter J. J. Huijgen[3] · John W. Cone[4] · Ana M. López-Contreras[2]

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Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Towards marine biorefineries: Selective proteins extractions from marine macroalgae *Ulva* with pulsed electric fields

Mark Polikovsky[a], Francois Fernand[a,b], Martin Sack[c], Wolfgang Frey[c], Georg Müller[c], Alexander Golberg[a,*]

Ruslana Rachel Palatnik

Uncertainty

- Feedstock cultivation
- Processing Technology
- Costs
- Contracting
- Prices of Substitutes
- Demand

The Max Stern
Academic
College of
Emek Yezreel

NRERC
המרכז לחקר משאבי טבע וסביבה
Natural Resources & Enviromental Research Center

Cultivation: Production per ha varies

No distinct patterns in the productivity of different farming systems

- neither in terms of production per unit of cultivation line
- nor in terms of production per unit of farming area

Reason

- farm locations
- Growing cycles
- Type of seaweed

Range of 6 -108 tonne/ha per year

Growth Rate Variation

- growth rate of *Kappaphycus*
- Same location, different farming systems
- Same farming system, different locations
- **from 0.2 to 10.86 percent per day**

- *Hayashi et al. (2010)*
- *FAO et al. (2013)*

Conversion factor (yield) varies (*Ulva*)

Biomass DW derived product	Conversion Factor	Reference
Ethanol [g m^{-2}]	0.03-0.23	Nikolaisen, et al. 2008, van der Wal, et al ., 2013
Buthanol	0.03-0.06	van der Wal, et al 2013
Acetone	0.01-0.02	Potts, T. et al. 2012; van der Wal, et al., 2013
Methane [m3/ tonDW]	10-96	Bruhn, et al., 2011
Protein [g m^{-2}]	0.18	Abudabos et al. 2013, van der Wal, et al 2013
Energy [KJ m^{-2}]	19	Yantovski, 2008
Kg CO_2 per KWh of natural gas	0.54	EPA

(Source: Lehahn et al. 2016)

	ENAlgae2015	FAO 2013	Konda et al 2015	Korzen et al 2015	Seghetta et al 2016	
macroalgae (seaweed)	Brown: Laminaria Digitata	Red: Kappaphycus And Eucheuma	Brown: Saccharina Latissima	Green Ulva Rigida	Brown: Laminaria Digitata	Brown: Saccharina Latissima
country	Ireland, UK, France, Holland	Philippines, Indonesia, Tanzania, India, Mexico, Solomon Islands	simulation	Israel	Denmark	
Output	Seaweed	Carrageenan, Gracilaria (primary raw materials for agar) and nori	co- production ethanol and alginate	DDGs fish feed and ethanol	co-production: ethanol, liquid fertilizer, fish feed	
growth rate average	10 kg WW/m longline	8-57 WW ton/year/ha		15% daily average growth rate WW	average productivity of 10 Mg WW/ha	average productivity of 1.5 Mg WW/ha
season	twice a year, winter	4 to 8 cycles a year	NA	April-October	Summer	
DW/WW ratio				1/9	1/3	1/6
Yield		Average 0.25	0.15 ethanol	0.12 ethanol 0.6 DDGs	0.005	0.13
costs:	simulated	actual	NREL - simulated	NREL - simulated	NREL - simulated	

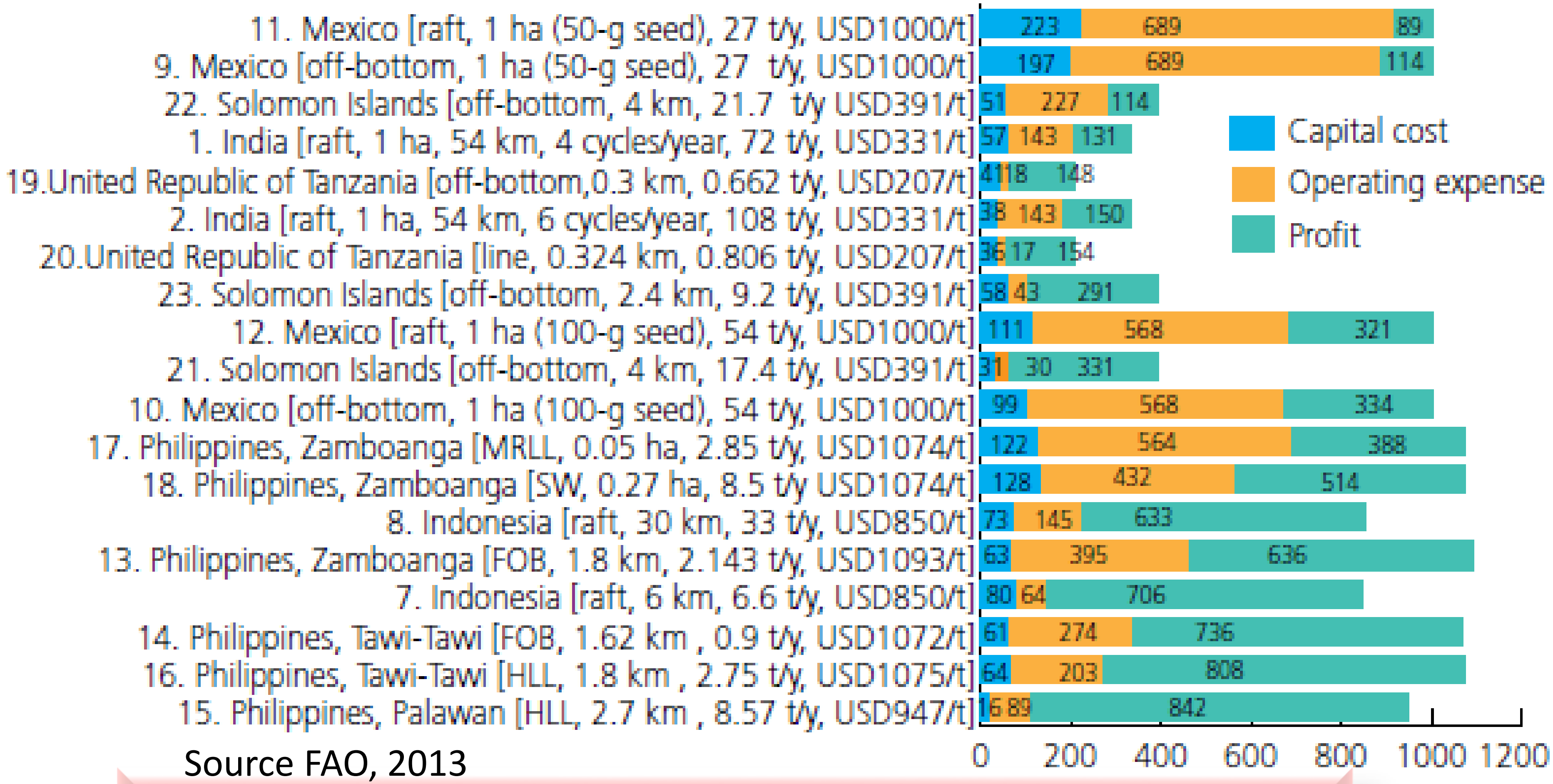
cultivation

refinery

Cultivation and refinery

	ENAlgae2015	FAO 2013	Konda et al 2015	Korzen et al 2015	Seghetta et al 2016
Conversion technology	not assessed	not assessed	no pre-treatment, hedrolysis and fermentation	no pre-treatment, single step for the release of glucose, simultaneous fermentation to ethanol	bioethanol production using separate hydrolysis and fermentation (SHF);
price to farmer $/ton DW	9944	500-1000	100 (21-120)	630	
r	r - 5.5%, insurance 0.5%		irr 10%	5%	
reported profitability indicator	Cost per kg WW to selling price	profit - positive in all cases	MESP $6.5–10.5/gal ethanol; MSP $ 3.1 alginate (?)	NPV profitable at large scale	**LCA** ,externalities, no profitability reported; potential for carbon sink, but also for increase in human toxicity (cancer)
price of output	~$10,000/ton DW	$2500/ton average	MESP $8.5/gal ethanol, $3.1/kg alginate	500-5000$ DDGS, $79/ton ethanol	

Profitability of carrageenan seaweed farming



Source FAO, 2013

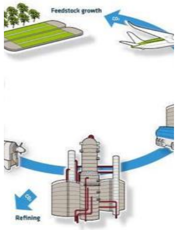
Open markets, but the price varies

Analytical needs

Scientific challenge

Multidisciplinary effort: how can we reduce the costs and increase yield?

More research on big scale cultivation (take into account market prices for seaweed)



Economic research on generic supply chain of cultivation AND refinery

Transparency and replicability

Outline of the Study in Progress

- Develop an Analytical model
- Run Simulations for Parameters
- Apply real data (collected these days)

Conceptual Framework

- 2 stages of production:
- 1st stage: Marine farming of seaweed
- 2nd stage: biorefinery utilizes seaweed input to produce outputs (sugars, proteins…)
- Cost functions with learning by doing at each stage
- The producer goal is to maximize profit by determining the volume of seaweed and shares of final outputs subject to volatile prices

Learning by doing cost functions

$$C_a = \frac{A x_a^{\phi}}{X_{a,cum}{}^{\psi}};\ C_b = \frac{B x_b^{\xi}}{X_{b,cum}{}^{\zeta}}; C = J\frac{x_a + x_b}{\left(X_{a,cum} + X_{b,cum}\right)^{\mu}}$$

for some $\phi > 1, \xi > 1$ and $\mu < 1$.

- $X_{a,cum}$ is the cumulative production of proteins,
- x_a is the production of proteins at this particular moment. Similarly for *b*
- *ψ, ζ, μ are the elasticities of learning by-doing that define the effectiveness with which the learning process takes place*
- *A, B and J are costs of the first unit produced*

Dynamic Profit maximization

$$\max_{x_a,x_b} \pi = \int_T^{\infty} \left(P_a\, x_a + P_b\, x_b - A \frac{x_a^{\phi}}{{X_{a,cum}}^{\psi}} - B \frac{x_b^{\xi}}{{X_{b,cum}}^{\zeta}} \right.$$

- $P_a(t)$ and $P_b(t)$ the prices of outputs a and b respectively.
- r - discount factor

First order conditions

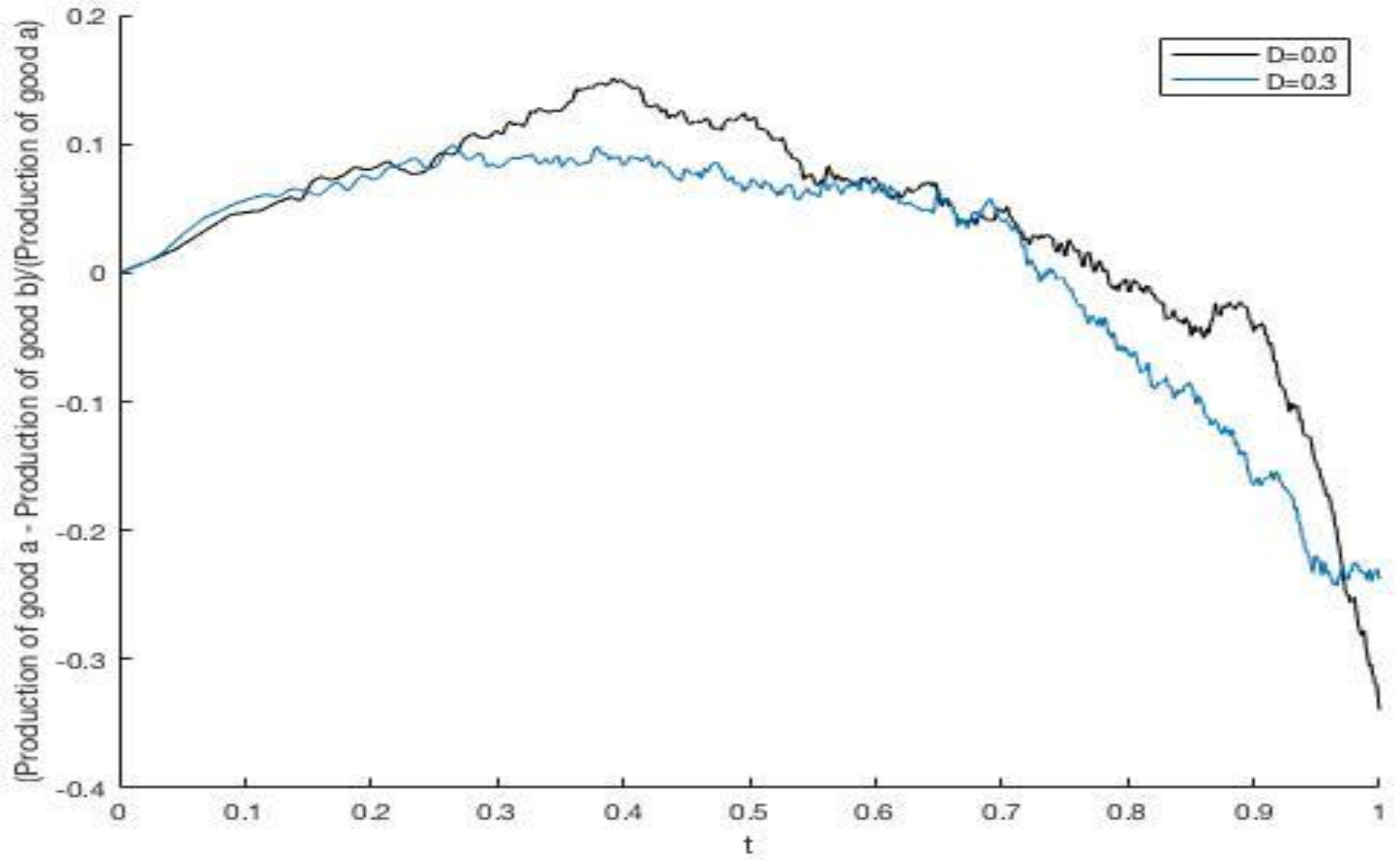
$$\begin{cases} \psi A \dfrac{x_a^{\phi}}{{X_{a,cum}}^{\psi+1}} - \phi A \dfrac{(\phi-1)x_a^{\phi-2}\ddot{x}_a X_{a,cum} - \psi x_a^{\phi}}{{X_{a,cum}}^{\psi+1}} - r\phi A \dfrac{x_a^{\phi-1}}{{X_{a,cum}}_a^{\psi}} - \dfrac{Dr}{\left(X_{a,cum} + X_{b,cum}\right)^{\mu}} + \dot{P}_a + rP_a = 0 \\ \zeta B \dfrac{x_b^{\xi}}{{X_{b,cum}}^{\zeta+1}} - \xi B \dfrac{(\xi-1)x_b^{\xi-2}\ddot{x}_b X_{b,cum} - \zeta x_b^{\xi}}{{X_{b,cum}}^{\zeta+1}} - r\xi B \dfrac{x_b^{\xi-1}}{{X_{b,cum}}_b^{\zeta}} - \dfrac{Dr}{\left(X_{a,cum} + X_{b,cum}\right)^{\mu}} + \dot{P}_b + rP_b = 0 \end{cases}$$

$$\ddot{x}_a - growth\ ratio\ of\ production - first\ derivative\ of\ x_a$$

Simulation parameters

- learning rates of 4% on average for mature technologies such as coal, oil and lignite
- new renewable energy technologies such as solar photovoltaic energy exhibit high rates, around 20% on average. (Kahouli-Brahmi, 2008)
- $\xi = 1.2, \psi = \zeta = 0.5, \mu = 0.4.$
- For simplicity $A = B = 1.$
- the change in prices is uniform, random with zero expected value.

Simulation Results Preview



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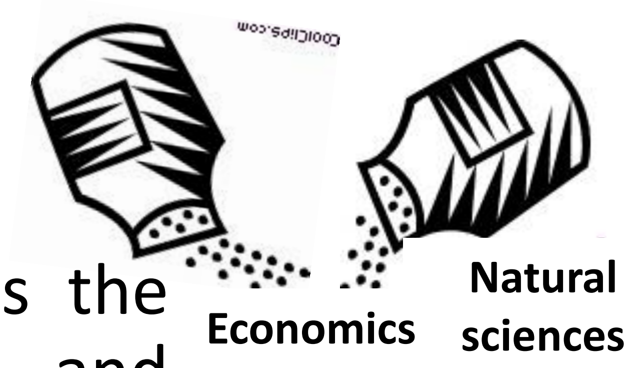
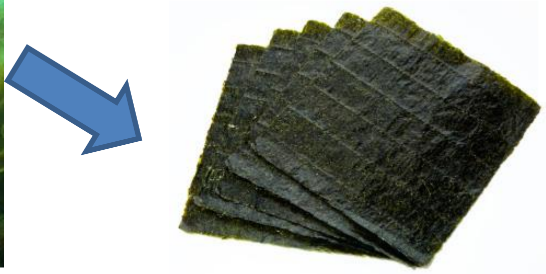
What is Next?



- apply this concept model to assess the profitability of producing biofuels and proteins from macroalgae under various conditions.
- Identify what should be:
  - the learning rate, yield, relative prices, shares of co-products

for profitable production in the near future



When nothing is going right,

go left

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