Forest roads planning and management in terms of Social-Ecological Systems (SES) framework

A Kantartzis¹, G Arabatzis¹, O Christopoulou², A Sfougaris³, S Sakellariou³, Ch Malesios⁴, E Tsiaras⁵, F Samara² and S Th Tampekis⁵,⁶

¹ Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, 193 Pantazidou St., 68200, Orestiada, Greece
² Department of Planning and Regional Development, University of Thessaly, Pedion Areos, 38334, Volos, Greece
³ Department of Agriculture Crop Production, University of Thessaly, 38446, Volos, Greece
⁴ Department of Agricultural Economics and Rural Development, Agricultural University of Athens, 75 Iera Odos St., 11855, Athens, Greece
⁵ Region of Epirus, Governor's Office, 45221, Ioannina, Greece
⁶ Corresponding author email: stampeki@gmail.com

Abstract. Adaptation to climate change as well as the increasing demand for a new approach in post fire socioecological resilience and Nature-Based Solutions (NBS) in forest management requires a different way of thinking of forest roads planning, in terms of Social-Ecological Systems (SES) Framework. Social-ecological systems are complex, adaptive and emphasize that social and ecological systems are linked through feedback mechanisms, and that both display resilience and complexity. In this frame, it is important to clarify the considerable dynamic elements for the future development of forest roads planning and management that promote natural, socio-economic, and cultural well-being. The main objective of this paper is to identify important new challenges concerning the forest roads planning and management and to propose a conceptual paradigm towards SES in a continuing changing climate, social needs and environmental conditions. Hence, a newly developed concept under the prism of SES forest roads planning, is presented. Eight key performance areas to ensure the forest operations as SES include: (i) nature’s services; (ii) ergonomics; (iii) environmental economics; (iv) quality optimization of products and production based on NBS; (v) the use as evacuation routes; (vi) access to renewable energy sources; (vii) people and society; and (viii) resilience. The conceptual frame of SES provides a close to nature perspective which addresses the ongoing and foreseeable challenges that the global forest ecosystems face, based on harmonized forest operations performance across economic, environmental and social sustainability. In this new concept, we demonstrate how these eight interconnected principles interact to each other and are related to forest operations achieving Nature Based Solutions in forest management and climate change mitigation.
1. Introduction
The environmental pressures and the social sustainability challenges that humanity and our planet face in the 21st century are clearly and deeply intertwined. These challenges result from the assemblance and interaction of multiple, mutually reinforcing social and ecological processes at multiple scales [1], where social procedure includes economic, political, cultural and technological actions, and ecological processes that include biotic (e.g. interactions between flora and fauna dynamics, human activity) and abiotic (e.g. nutrient flows, climate patterns) processes. The recognition that environmental and social sustainability are highly demand issues, and that they also are inherently systemic and intertwined, as well as the escalating urgency to address these challenges, have driven a paradigm shift in how social and natural systems are studied [2].

In most scientific disciplines, humans and nature have been treated as separate entities [1]. However, in recent decades, this way of thinking has been widely contested and is changing, partly influenced by the rise in systems sciences and complexity thinking [3]. Researchers in different sciences and disciplines are progressively viewing human systems as interdependent, inseparable and intertwined with ecosystems, entrenched within and dependent upon the biosphere and the broader Earth system [1,4,5]. Furthermore, there is a growing awareness of the need for knowledge production processes that account for and engage with the complex interconnections and interplay between the social and the ecological, and the emergent and often unexpected processes, features, problems and opportunities to which they give rise [3].

‘Social-ecological systems’ (SES) is an emerging concept for understanding the intertwined nature of human and natural systems in this new, interconnected and interdependent way. In the early to mid-1990s the SES concept developed through collaboration of scientists working in the interdisciplinary areas of ecological economics and common-pool resource systems [6,7,8]. Specifically, the volume Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience combine a systems approach and an adaptive management with a focus on dynamic institutions and diverse systems of property rights, with 14 case studies analysing ecological resilience and local and traditional systems engaged in ecosystem management [9]. The concept of SES is based on the idea that ‘the delineation between social and natural systems is artificial and arbitrary’ [9], emphasising that people and nature are intertwined. Nature no longer merely sets the space in which social interactions take place; likewise, people are not just an external driver in ecosystem dynamics [10,2]. Social-ecological systems are therefore not merely social plus ecological systems, but cohesive, integrated systems characterised by strong connections and feedbacks within and between social and ecological components that determine their overall dynamics [10,11].

There is growing awareness that “nature-based solutions” (NbS) can help to protect us from climate change impacts while slowing further warming, supporting biodiversity, and securing ecosystem services [12, 13]. They are also increasingly seen as opportunities for sustainable investments. NbS actions are actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits [12].

They play a vitally important role to mitigate and adapt to climate change, but are not a substitute for a rapid fossil fuel phase-out and must not delay urgent action to decarbonize our economies. NbS involve the protection and/or restoration of a wide range of naturally occurring ecosystems on land and in the sea.

Several publications have appeared in recent years documenting that forest road network layout, transportation systems, and harvesting operations are strategic principles for the sustainable management and socioeconomic development of forest areas [14,15].

In previous years, many researchers have published their work, presenting the optimal planning of harvesting, logging operations, transportation systems, and their management strategies that comprise the basic principle in order to minimize environmental impacts, as well as to satisfy the need for the utilization and protection of forest resources [16,17,18,19,20,21]. The qualitative evaluation and optimization of forest road network that aim at the minimization of total life cycle costs and
environmental impacts are very important for the sustainable management of forests [22,23]. Therefore, designers of forest operations should design timber harvesting activities after considering not only the efficiency costs but also their environmental impacts [24,25]. Geometric models of transportation networks such as road spacings or densities have been used to identify optimal design criteria. In order to plan the ideal forest road network, important role can play both the optimal road density and the optimal length [26,27,28]. Hence, the cost of wood transportation and the construction of forest roads should be balanced with the existence of a suitable forest road network that gives access to the forest, and at the same time to have the minimum possible length and the optimum road density and road spacing [29,30,31,32,33,34,35].

The forest road network planning for multiple objectives depends on three objective function (life cycle costs, adverse ecological effects, and landing attractiveness) [22] needs, therefore, a new method for the forest road planning that includes financial, ecological, and social parameters is needed to be developed [14]. Consequently, a functional approach of forest road planning and for optimization of relative parameters (economic and environmental) is necessary [22].

2. Methodology
This study describes a contemporary approach of forest roads planning and management in terms of Social-Ecological Systems (SES) Framework which is based on a broader focus and different scales that harmonize the interaction among economy, ecology and society (Fig. 1).

Figure 1. Forest roads planning and management in terms of Social-Ecological Systems (SES) Framework.

The new concept of forest roads planning and management is defined as a complex system of interconnections and interplay between the social and the ecological relationships in forest operations
planning, management, implementation, monitoring and improvement with the consideration of eight performance areas including: (i) nature’s services; (ii) ergonomics; (iii) environmental economics; (iv) quality optimization of products and production based on NBS; (v) the use as evacuation routes; (vi) access to renewable energy sources; (vii) social-ecological; and (viii) resilience. The eight performance areas are presented:

i) **NATURE’S SERVICES**: The mitigation of environmental pressures due to forest operations at the local, regional and global scale should be minimized. Environmental considerations are offered via solutions that limit impacts of forest operations on: Ecosystem services, Energy consumption, Soil, Air: Water, Remaining stand and regeneration capacity.

ii) **ENVIRONMENTAL ECONOMICS**: Forest operations should be profitable in order to improve the entire forest management process.

iii) **ERGONOMICS**: Forest operations can be considered in the context of SES only if forest workers are safeguarded and protected from undue risks. Ergonomics in forest operations includes the comfort of operations through the application of modern means and techniques, adapted to the specific contexts, but it also pursues the health and safety of forest workers[36]. Forest workers awareness raising about their health and safety conditions.

iv) **QUALITY OPTIMIZATION OF PRODUCTS AND PRODUCTION BASED ON NBS**. Nature-based Solutions (NbS) are defined by IUCN as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits[12]. Hence, reducing waste materials, and enhancing product quality and profitability during forest roads planning and management should be the observation tasks.

v) **THE USE AS EVACUATION ROUTES**. Forest roads can be used as wildfires evacuation routes planning. Especially, in WUI (Wild-Urban Interfaces). During the catastrophic wildfire in Mati, Eastern Attica, June 2018 Professor Costas Synolakis at his study, using simulation models based on agent-based modelling has made good use of forest roads as evacuation roads.

vi) **ACCESS TO RENEWABLE ENERGY SOURCES**. The close to nature management of forest resources can only be achieved through a well-organized road network designed with the optimal spatial planning and the minimum environmental impact[27,50].

vii) **SOCIAL-ECOLOGICAL**. Forest services include a wide range of ecological, political, economic, social and cultural systems and processes that are necessary for people and society[37]. Forest operations should be planned and managed harmonized with forest services and functions. Hence under the prism of ‘Social-ecological systems’ (SES) that are an emerging concept for understanding the intertwined nature of human and natural systems in this new, interconnected and interdependent way. According to a recent review[38,39], describes six organising principles of complex adaptive systems that help to further inform our understanding of the nature of SES are described:

- The first one is that in these systems the relations and interactions between the elements of the system are more important to understanding the properties and behavior of an SES than the properties of the individual components of the system themselves.
- They having the ability to change constantly, to suit the changing conditions. This is the second principle. The numerical interrelations in the system create feedback mechanisms that enable an SES to continuously adjust and adapt to changing conditions, brought about either by the system itself or by external forces.
- The third critical feature of SES is that the dynamic interactions within the system are often non-linear. This can cause large and surprising effects from small changes, and vice versa[39,40,41,3].
- The fourth component is that they do not have clear boundaries. Due to the extensive interactions and connections between an SES and its broader environment, it is very difficult to discern which components belong inside the system and which belong to the broader environment. Deciding on system boundaries therefore often depends on the purpose of the study and the perspective of the observer[42].
- Linked to above principle is the fifth feature, the dependent context of the SES. As the context changes, the system will change and the system components may take on a different role or function.

- Finally, SES are characterised by complex causality and emergence. The cause and the effect in SES are not unidirectional or linear, but they are marked by complex recursive causal pathways. Social-ecological systems therefore cannot be understood nor can their behavior be predicted based solely on information relating to their individual parts. Many emergent system properties are inherently unpredictable as they involve non-linear effects, learning, evolution, novelty and innovation.

viii) RESILIENCE. Resilience provides the capacity of a system to absorb shocks while maintaining function. When change appears, resilience gives the components the opportunity for renewal and reorganization. In a resilient system, change has the potential to create opportunity for development, novelty and innovation. Managing the resilience enhances the likelihood of sustaining development in changing environments where the future is unpredictable and surprise is likely.

3. Results and discussion

The main objective of this paper is to underline the important new challenges concerning the forest roads planning and management and to propose a conceptual paradigm towards SES in a continuing changing climate, social needs and environmental conditions. Hence, a newly developed concept under the prism of SES forest roads planning, is presented. Eight key performance areas to ensure the forest operations as SES include: (i) nature’s services, (ii) ergonomics, (iii) environmental economics, (iv) quality optimization of products and production based on NBS, (v) the use as evacuation routes, (vi) access to renewable energy sources, (vii) social-ecological, and (viii) resilience.

The conceptual frame of SES provides a close to nature perspective which addresses the ongoing and foreseeable challenges that the global forest ecosystems face, based on harmonized forest operations performance across economic, environmental and social sustainability. In this new concept, we demonstrate how these eight interconnected principles interact to each other and are related to forest operations achieving Nature Based Solutions in forest management and climate change mitigation.

4. Conclusions

Adaptation to climate change as well as the increasing demand for a new approach in post fire socioecological resilience and Nature-Based Solutions (NBS) in forest management requires a different way of thinking of forest roads planning, in terms of Social-Ecological Systems (SES) Framework. In this frame, it is important to clarify the considerable dynamic elements for the future development of forest roads planning and management that promote natural, socio-economic, and cultural well-being.

This new approach seeks to apply an effective and practical concept of close to nature forest operations while considering the Anthropocene. In navigating research, action and decision-making processes in the Anthropocene, the relational interdependencies of SES should always be acknowledged. Complex adaptive systems-based approaches describe a need for different procedure and call for more inclusive and integrative modes of engaging with real-world SES problems that acknowledge the intertwinedness of humans and nature, the limits of what is knowable and how we can act to effect change in complex SES. Complex adaptive systems-based approaches call for participatory and collaborative multi-stakeholder processes that foster dialogue and knowledge co-creation, and the development of more systemic awareness. In this frame of SES concept, a holistic approach to setting key indicators for the eight performance areas are defined above.

The acknowledgment that social and ecological systems are inseparable, and function as intertwined complex adaptive systems, offers scientists, policymakers and scholars an alternative aspect for studying and engaging with the complex challenges that arise from human–nature interactions.
The social-ecological action situation (SE-AS) framework is a recent development that further develops Ostrom’s concept of an action-situation and gives emphasis to social-ecological interactions and how they increase emergent phenomena such as regime shifts or sustainable ecosystem management [19].

The conceptual frame of SES provides a close to nature perspective which addresses the ongoing and foreseeable challenges that the global forest ecosystems face, based on harmonized forest operations performance across economic, environmental and social sustainability. In this new concept, we demonstrate how these eight interconnected principles interact to each other and are related to forest operations achieving Nature Based Solutions in forest management and climate change mitigation.

References
[1] Folke C, Biggs R, Norström A V, Reyers B and Rockström J 2016 Social-ecological Resilience and Biosphere-based Sustainability Science *Ecology and Society* **21** (3) 41, doi:10.5751/ES-08748-210341
[2] Schoon M L and Leeuw S van der 2015 The Shift Toward Social-Ecological Systems Perspectives: Insights into the Human-Nature Relationship *Natures Sciences Sociétés* **23** (2) 166–74, doi:10.1051/ nss/2015034
[3] Preiser R, Biggs R, De Vos A and Folke C 2018 Social-Ecological Systems as Complex Adaptive Systems: Organizing Principles for Advancing Research Methods and Approaches *Ecology and Society* **23** (4) 46, doi:10.5751/ES-10558-230446
[4] Reyers B, Folke C, Moore M L, Biggs R and Galaz V 2018 Social-Ecological Systems Insights for Navigating the Dynamics of the Anthropocene *Annual Review of Environment and Resources* **43** 267–89, doi:10.1146/annurev-environ-110615-085349.
[5] Schlüter M L, Haider J, Lade S J, Lindkvist E, Martin R, Orach K, Wijermans N and Folke C 2019 Capturing Emergent Phenomena in Social-Ecological Systems – An Analytical Framework *Ecology and Society* **24** (3) 11, doi:10.5751/ES-11012-240311
[6] Berkes F, ed., 1989 *Common Property Resources: Ecology of Community-based Sustainable Development* (London: Belhaven Press)
[7] Ostrom E 1990 *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge: Cambridge University Press)
[8] Costanza R, ed. 1991 *Ecological Economics: The Science and Management of Sustainability* (New York: Columbia University Press)
[9] Berkes F and Folke C, eds. 1998 *Linking Social and Ecological Systems: Management Practices and Short Mechanisms for Building Resilience* (Cambridge: Cambridge University Press)
[10] Folke C, Jansson A, Rockström J, Olsson P, Carpenter S R, Chapin F S, Crépin A S et al. 2011 Reconnecting to the Biosphere *Ambio* **40** (7) 719, doi:10.1007/s13280-011-0184-y
[11] Biggs R, Schlüter M and Schoon M L 2015 An Introduction to the Resilience Approach and Principles to Sustain Ecosystem Services in Social-Ecological Systems *Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems*, edited by R. Biggs, M. Schlüter, and M.L. Schoon (Cambridge: Cambridge University Press) 1–31
[12] Cohen-Shacham E, Walters G, Janzen C and Maginnis S (eds.) 2016 *Nature-based Solutions to address global societal challenges* Gland, Switzerland: IUCN. xiii + 97 pp, ISBN: 978-2-8317-1812-5, DOI: http://dx.doi.org/10.2305/IUCN.CH.2016.13.en
[13] Seddon N, Chausson A, Berry P, Girardin C A J, Smith A and Turner B 2020 Understanding the value and limits of nature-based solutions to climate change and other global challenges *Philosophical Transactions of the Royal Society* **375** 20190120
[14] Akay A E, Wing M G, Sivrikaya F and Sakar D 2012 A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean region of turkey *Environmental Monitoring and Assessment*, *Springer* **184** (3) 1391–407
[15] Makhdoum M F 2008 Landscape ecology or environmental studies (Land Ecology) Journal of International Environmental Application & Science 3 (3) 147–60

[16] Epstein R, Weintraub A, Sapunar P, Nieto E, Sessions J B, Sessions J, Bustamante F Aand Musante H 2006 A combinatorial heuristic approach for solving real-size machinery location and road design problems in forestry planning Operations Research 54 (6) 1017–27

[17] Sakellariou S, Parisien M A, Flannigan M, Wang X, de Groot B, Tampeksis S, Samara F, Sfougaris A and Christopoulo O 2020 Spatial planning of fire-agency stations as a function of wildfire likelihood in Thasos, Greece Science of The Total Environment 729 (10) 139004, https://doi.org/10.1016/j.scitotenv.2020.139004

[18] Sakellariou S, Samara F, Tampeksis S, Sfougaris A and Christopoulo O 2019 Development of a Spatial Decision Support System (SDSS) for the active forest-urban fires management through location planning of mobile fire units Environmental Hazards 1-21, https://doi.org/10.1080/17477891.2019.1628696

[19] Tampeksis S, Samara F, Sakellariou S, Sfougaris A and Christopoulo O 2018 An eco-efficient and economical optimum evaluation technique for the forest road networks: The case of the mountainous forest of Metsovo, Greece Environmental Monitoring and Assessment, Springer 190 (3) 134-49, ISSN: 0167-6369, DOI: 10.1007/s10661-018-6526-5

[20] Wegner K F 1984 Foresty handbook Second Ed (New York etc. Wiley) p 1335

[21] Zamora-Cristales R, Sessions J, Boston K and Murphy G 2015 Economic optimization of forest biomass processing and transport in the Pacific Northwest USA Forest Science 61 (2) 220–34

[22] Stückelberger J A, Heinimann H R and Burlet E C 2006 Modelling spatial variability in the life-cycle costs of low volume forest roads European Journal Forest Research 125 (4) 377–90, https://doi.org/10.1007/s10342-006-0123-9

[23] Záček J and Klč P 2008 Forest transport roads according to natural forest regions in the Czech Republic Journal of Forest Science 54 (2) 73–83

[24] Han H S, Oneil E, Bergman R D, Eastin I L and Johnson L R 2015 Cradle-to-gate life cycle impacts of redwood forest resource harvesting in northern California Journal of Cleaner Production 99 217–9

[25] Larsen M C and Parks J E 1997 How wide is a road? The association of roads and mass-wasting in a forested mountain environment Earth Surface Processes and Landforms 22 (9) 835–48

[26] Matthews D M 1942 Cost control in the logging industry American forestry series: New York McGraw-Hill p. 374

[27] Tampeksis S, Sakellariou S, Samara F, Sfougaris A, Jaegrer D and Christopoulo O 2015a Mapping the optimal forest road network based on the multicriteria evaluation technique: the case study of Mediterranean Island of Thassos in Greece Environmental Monitoring and Assessment 187 (11) 687–704, https://doi.org/10.1007/s10661-015-4876-9

[28] Tampeksis S, Samara F, Sakellariou S, Sfougaris A and Christopoulo O 2015b Mapping the Optimal Access to the Natural Resources Based on Spatial Planning. The Case Study of Thassos Island, Greece International Journal of Innovative Technology and Exploring Engineering (IJITEE), Blue Eyes Intelligence Engineering & Sciences Publication Pvt. Ltd. ISSN: 2278-3075, 5 (3) 63

[29] Matthews D M 1939 The use of unit cost data in estimating logging costs and planning logging operations Journal of Forestry 37 (10) 783–7

[30] Olsson L 2004 Optimisation of forest road investments and the roundwood supply chain. Department of Forest Economics Umea, Doctoral thesis, Swedish University of Agricultural Sciences Umea, Acta Universitatis Agriculturae Sueciae. Silvestria, 1401-6230, 310. ISBN 91-576-6544-3

[31] Olsson L and Lohmander P 2005 Optimal forest transportation with respect to road investments Forest Policy and Economics 7 (3) 369–79

[32] Segebaden G V 1964 Studies of cross-country transport distances and road net extension Studia
[33] Soom E 1952, Rückafwand und Wegabstand beim Rücken von Brennholz Schweizerische Zeitschrift für Forstwesen 102 (8)

[34] Sundberg U 1963 The economic road standard, road spacing and related questions. Some views on the theory of planning a forest road network in non-alpine conditions Proceedings, Symposium on the Planning of Forest Communication Networks (Roads and Cables) pp 231-47, (Genève: Joint committee on Forest working techniques and training of Forest Workers)

[35] Tan J 1992 Planning a forest road network by spatial data handling-network routing system Acta Forestalia Fennica 227 1–85

[36] Jafry T and O'Neil D H 2000 The application of ergonomics in rural development: a review Applied Ergonomics 31 (3) 263–8

[37] La Notte A, D'Amato D, Mäkinen H, Paracchini M L, Liquete C, Ego B, Geneletti D and Crossman N D 2017 Ecosystem services classification: a systems ecology perspective of the cascade framework Ecological Indicators 74 392–402

[38] Biggs R, Rika Preiser A de V, Clements H, Maciejewski K and Schlüter M 2021 Taylor and Francis, The Routledge Handbook of Research Methods for Social-Ecological Systems, DOI https://doi.org/10.4324/9781003021339, eBook ISBN9781003021339

[39] Levin S A, Xepapadeas T, Crépin A S, Norberg J, Zeeuw A D, Folke C, Hughes T, et al. 2013 Social-Ecological Systems as Complex Adaptive Systems: Modeling and Policy Implications Environment and Development Economics 18 (2) 111–32, doi:10.1017/S1355770X12000460

[40] Olsson P, Galaz V and Boonstra W J 2014 Sustainability Transformations: A Resilience Perspective Ecology and Society 19 (4) 1, doi:10.5751/ES-06799-190401

[41] Olsson P, Gunderson L H, Carpenter S R, Ryan P, Lebel L, Folke C and Holling C S 2006 Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems Ecology and Society 11 (1) 18, www.ecologyandsociety.org/vol11/iss1/art18

[42] Cilliers P 2001 Boundaries, Hierarchies and Networks in Complex Systems International Journal of Innovation Management 5 (2) 135–47, doi:10.1142/S1363919601000312

[43] Gunderson L H and Holling C S 2002 Panarchy: Understanding Transformations in Human and Natural Systems (Washington: Island Press)

[44] Berkes F, Colding J and Folke C 2003 Navigating Social-Ecological Systems: Building Resilience for Complexity and Change (Cambridge: Cambridge University Press)

[45] Holling CS 1973 Resilience and Stability of Ecological Systems Annual Review of Ecology and Systematics 4 1–23, doi:10.1146/annurev.es.04.110173.000245

[46] Pisano U 2012 Resilience and Sustainable Development: Theory of resilience, systems thinking and adaptive governance European Sustainable Development Network Quarterly Report 26

[47] Hammond D 2005, Philosophical and Ethical Foundations of Systems Thinking TripleC 3 (2) 20-7, doi:10.31269/triplec.v3i2.20

[48] Binder CR, Hinkel J, Bots P W G and Pahl-Wostl C 2013 Comparison of Frameworks for Analyzing Social-Ecological Systems Ecology and Society 18 (4) 26, doi:10.5751/ES-05551-180426

[49] Reyers B, Folke C, Moore M L, Biggs R and Galaz V 2018 Social-Ecological Systems Insights for Navigating the Dynamics of the Anthropocene Annual Review of Environment and Resources 43 267–89, doi:10.1146/annurev-environ-110615-085349

[50] Tsiaras E, Papadopoulos D, Antonopoulos C, Papadakis V and Coutelieris F 2020 Planning and assessment of an off-grid power supply system for small settlements Renewable Energy 149 1271-81