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Agro-Pruning for Energy as a Link between Rural Development and Clean Energy Policies

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Abstract: Agrarian pruning and plantation removal (APPR) is a common residue from pomo-technical maintenance of orchards, vineyards, and olive groves, frequently overlooked by the energy sector. This paper sheds new light on the socio-economic role of APPR as solid biofuel. The paper suggests business models that could both alleviate energy poverty in rural areas and increase the competitiveness of perennial crop (fruits, olives, vine) production. The effects of mobilizing APPR potential via business models are estimated at the micro (households' income) and macro (number of households affected, size of the investment, tax effect, CO_{2eq} savings) levels in the Croatian setting. Contrary to classical energy planning, the paper provides an approach that fosters local use of bioenergy by linking rural development with renewable energy end-use. The approach linked pruning energy potential with 47% of Croatian rural households which allows creating an evidence-based policy for rural development utilizing APPR as a sustainable solid biofuel. The most attractive business model for Croatian rural areas is utilization of APPR as a solid biofuel. It could be used as an energy poverty alleviation measure, allowing savings per heating season equivalent to 5%–11% of the average disposable income per household. Net APPR influence at VAT tax is estimated at 5.5 million euro·y^{-1}. The paper proves that using average values for APPR in energy planning could be misleading.

Keywords: pruning; solid biofuel; energy poverty; rural development; energy planning

1. Introduction

Energy potential from woody biomass originated from regular care of orchards, vineyards, and olive groves is frequently overlooked both at the micro (local source of renewable energy and additional farm income) and macro (energy planning) levels. The research that looks at bioenergy potential from agriculture at a macro level is focused on more abundant agro-residues from crop production (e.g., straw) [1–4] and manure [5,6]. Numerous studies have been conducted to estimate the energy potential from agrarian pruning and plantation removal (APPR) focusing either on a geographical area (country [7], region [4], macro-region [8–11]) or on a certain type of APPR from vineyards [7,12], specific fruit plantation [13], or olive groves [14,15]. Indeed, when comparing the energy potential from APPR to the energy demand in the same geographical area, the percentage of potential replacement of fossil fuels is negligible. For illustration, theoretical pruning potential estimated at 227.2 PJ·y^{-1} [10] represented 0.33% of the total energy supply in the EU-28 2017 [16]. Adding to that spatial distribution, seasonal dynamics, and variation in quality and quantity, APPR does not represent an attractive "low hanging fruit" to decarbonize our society, from that perspective.

This paper sheds a different light on the socio-economic role of using APPR as solid biofuel by creating business models that could help alleviate energy poverty in rural areas or increase the competitiveness of fruit, olive, and wine production. Namely, when connecting energy supply contained in APPR with the end-use energy demand at the location where such biomass originates, the setting is quite different. If APPR is used for heating of the EU-28 rural households, they could supply 11.55% and 50% of space and water heating demand, respectively [17]. This estimation is based on 64.1% and 14.8% of space and water heating, respectively, in the final energy consumption in the EU-28 households [17]. In Croatia, 28% of the population lives in rural areas, of those 80% live in family houses [18]. Yet, heating consumption among EU-28 varies from 15.7–20 koe·m^{-2} in Latvia and Hungary to less than 5 koe·m^{-2} in Spain, Portugal, and Malta [19]. Only connecting APPR with heating consumption would be also misleading as Latvia and Hungary have 5.9 kha and 2368 kha under permanent crops for human consumption, respectively [20]. Currently, EU-28 uses 14% of oil and petroleum products in the final energy consumption in the residential sector for space heating in 2017 [16]. The niche setting of using APPR as a renewable, locally available solid biofuel for rural household heating is different than the wider view from the energy balances.

Parallel to the energy aspects of APPR, our approach discusses different business models of APPR use that would motivate mobilization of APPR potential. A business model describes the rationale of how an organization creates, delivers, and captures value [21]. This paper contributes to the descriptive elaboration and economic analysis of the business model of APPR. The attractiveness of the business model would determine its replicability rate in a given legal and socio-economic setting. Existing knowledge provides several well-elaborated and verified frameworks of business models, design patterns, and tools to build a business model. Although many case studies revealed several types of circular business actions or models, these models have limited transferability [22,23]. There are very few studies covering, in a more comprehensive manner, how a circular business model framework should look. Lewandovski (2015) investigated the eight sub-domains of research on circular business models to redefine the components of the business model canvas in the context of the circular economy [22]. None of these reviewed studies has provided satisfactory answers to the following questions: How may the principles of the circular economy be applied to a business model? This paper builds on stakeholders' responses on business models [24–26] recorded during the implementation of the uP_running project [27] in Croatia (2016-2019). It used the triple fit challenge [22] to assess the attractiveness of circular economy business models to the pruning owners. It aimed to unlock the European potential of woody biomass residues produced by APPR and guide policy makers on how to integrate its energy end-use as a solid biofuel, free of sustainability controversies. The project identified key stakeholders and suggested applicable business models based on the case studies around Europe in order to contribute sustainable energy use and farm competitiveness.

This paper lays out aspects of four main options on how to utilize APPR as solid biofuel that are further shaped in eight business models whose replicability rates will depend both on rational (e.g., economics, legal boundaries) and non-rational (human) factors [4,28]. The effects of mobilizing APPR potential via business models are estimated at the micro (disposable income) and macro (number of households affected, size of the investment, net VAT effect, energy balances impacts) levels for Croatian rural households. The selection met the triple fit challenge of a circular economy business canvas [22]. Finally, the paper provides a heuristic methodology that allows creating an evidence-based policy for rural development utilizing APPR as solid biofuel.

2. Materials and Methods

Mobilizing APPR as a bioenergy source requires a different approach than other biomass sources as the effects are greater at the rural development side than on the energy sector as a whole. The proposed stepwise approach creates synergy between (renewable) energy policy and rural development; it consists of the 8 steps, starting with the energy balances at the macro level, reaching as far as to the individual rural

household with a perennial grove and bringing the effects back to the macro level (Table 1). The approach concentrates on the effects of engaging an already available solid biomass source for bioenergy.

Each step is described in the following sub-sections, including formulas and sources on how to calculate and interpret the outputs.

Table 1. Stepwise approach in creating synergy between renewable energy and rural development policy in utilizing agrarian pruning and plantation removal (APPR) as solid biofuel.

Step	Action	Output
1	Linking APPR potential with energy demand at the location of origin	Share of APPR primary energy in final energy demand in rural households at the national level
2	Allocating APPR primary energy most suitable end-use	Household final energy consumption by fuel type and end-use of energy
3	Positioning APPR as fuel at the fuel market	Ranking of fuels by the gross price of energy
4	Defining business models with the highest replication probability	An outlook of feasible business models to utilize APPR as solid biofuel
5	Sizing the annual APPR demand with a size of the perennial grove	An average area of orchard, vineyard, and olive grove to meet the household's energy consumption by end-use of energy
6	Sizing replication rate	Estimation of the market for feasible business models
7	Estimating effects at the micro-level	Changes in household's income occurred by using APPR as solid biofuel
8	Estimating effects at the macro-level	Changes in VAT, energy imports, newly created demand for utilities; CO_{2eq} savings

2.1. Linking APPR Potential with Energy Demand at the Location of Origin

APPR potential will depend not only on the area covered with perennial crops but also on the thinning practice, season, and growing type (extensive, intensive). At this step, the theoretical potential range of winter APPR would suffice. The considered APPR potential is allocated from the uP_running project [27] with adaptation [29,30] to the net calorific (heating) value of the dry matter, to make it comparable with the values recorded as the energy balances [16]. Energy balances are considered a starting point for the development of energy sector policies [16].

Households represent one of the four sub-categories of "other" sectors that consume energy. The energy consumed by households is represented in the final energy demand of energy balances. Final energy demand is not directly comparable with theoretical APPR potential which represents primary energy contained in APPR as a fuel or energy carrier. Final energy is the energy that is used by a consumer, after reducing the primary energy of fuel for energy conversion, transformation, delivery, losses, etc. [16]. Assuming 80% efficiency of energy conversion for APPR, it is possible to relate the primary energy of APPR with energy consumption in rural households:

$$FE_{pruning} = PE_{pruning} \times \eta \qquad (1)$$

where $FE_{pruning}$ = final energy potential of pruning, $PE_{pruning}$ = theoretical energy potential of APPR, η = efficiency of energy conversions (%).

$$FEC_{rh} = FEC_{h} \times rh \qquad (2)$$

where FEC_{rh} = final energy consumption in rural households, FEC_{h} = final energy consumption in households, rh=share of rural households in total households (%).

$FE_{pruning}$ is comparable with FEC_{rh} and serves as a good indicator of how important a role energy from APPR could have in energy policies in rural areas. Further, APPR energy could be tailored towards specific use in the household: biomass as biofuel can be used for space and water heating as well as cooking.

To calculate the share of space heating, water heating, and cooking end-use of energy consumption in dwellings, respectively, the following formulas are used:

$$FECrhHEAT = FECrh \cdot \% \text{ space heating in end-use of energy consumption in dwellings} \quad (3)$$

$$FECrhWATER = FECrh \times \% \text{ water heating in end-use of energy consumption in dwellings} \quad (4)$$

$$FECrhCOOKING = FECrh \times \% \text{ cooking in end-use of energy consumption in dwellings} \quad (5)$$

All values are expressed in rounded numbers as they serve only as a guide towards the end-use of APPR.

2.2. Allocating APPR Primary Energy to the Most Suitable End-Use

To obtain energy demand structure, final energy consumption per rural household (FEC_{perRH}) is multiplied with shares of energy uses (space heating, water heating, space cooling, cooking, lighting and electrical appliances, and other end-uses (mainly covering uses of energy by households outside the dwellings themselves)). Eurostat [19] provides data on FEC_{perRH} at the EU-28 and member state levels, while the International Energy Agency (IEA) provides global level data. Part of the main energy products (end-use energy) in the final energy consumption in the households (FEC_h) for each type of end-use allows seeing the structure of fuels used for space heating, space cooling, water heating, cooking, lighting and appliance use, and other end-uses. APPR, as a solid biofuel, will find its place either as substituting oil and gas end-uses or supplementing renewables and wastes categories. It is very likely that space heating will take most of the final energy demand in rural households (FEC_{rh}) but Mediterranean rural areas would also use for other heat demand, such as cooking and hot water preparation. The share of fuels in the final energy consumption in the residential sector for space heating gives an overview of the fuel mixture used for space heating [19,20].

2.3. Positioning APPR as Solid Biofuel at the Fuel Market

To allocate the attractiveness of fuel switching, substitution, or supplement options for a rural household, gross energy prices per fuel for heating are compared. Gross energy prices represent the price paid per unit of energy by a household., considering the losses for energy conversion. It allows comparison of fuel prices not only by their primary energy content but also considering the losses that occurred for energy conversion.

Table 2 provides indicative coefficients to give a rough estimation on the market prices, if more precise data on heating systems are not available. It states the equivalent useful heat energy monetary value for each monetary unit of primary energy.

Table 2. Useful heat energy monetary equivalent to the fuel price by fuel type (source: own calculations based on reference [31]).

Type of Fuel for Heating	Energy Efficiency of the Conversion [31]	Useful (Heat) Energy Monetary Equivalent to the Fuel Price
Electricity	100%	100%
natural gas		
—old stoves	<75%	125%
—new stoves	75–85%	120%
LPG-propane butane	85% [32]	115%
LPG—butane	90%	110%
light heating oil	>90%	110%
fuelwood		
—old stoves	70–80%	130%
—new stoves	70–85%	120%
briquettes	85%	125%
pellets	>90%	110%

2.4. Defining Business Models with the Highest Replication Probability

In rural areas, households are usually set either in the vicinity of a farm or integrated within the farm facilities with a single connection point for energy supply (electricity, gas). An APPR owner has four options to utilize the primary energy captured in APRR: (1) use it in direct combustion to generate heat; (2) use direct combustion to generate both heat and electricity in a cogeneration (combined heat and power or CHP) unit; (3) produce agro-pellets for market; and (4) sell APPR.

The attractiveness of each option at the local level will depend, in accordance to the triple fit challenge [22], not only on the balanced cost and revenue streams but also on the age, education, and financial potency plus tradition, perceptions, and values on using APPR, as well as on the prices of the alternatives. The legal setting would also determine the feasibility of each option. Each of the business models is evaluated using the pay-back (PB) period—the amount of time it takes to recover the cost of an investment. Table 3 indicates the options for increasing competitiveness in the primary production of fruit, olives, and wine with APPR utilization

Table 3. Business models with cost and benefits.

Business Model	Costs	Benefits
Use APPR for direct combustion to generate heat		
Fuel supplement option	No investment needed.	Savings equivalent to the prices of wood logs
Fuel-switching option	Investment of 4730 euro [32] needed for heating system adaptations.	Savings for the household space heating equivalent to the fuels with gross energy prices higher than wood logs.
Direct combustion of APPR to generate both heat and electricity in a CHP unit	Investment for a 50 kW unit: 4700 euro/kW for CHP unit and 2 × 2500 W home chippers at 250 euro each. Total investment: 235,500 euro. Additional costs for heating system adaptations per household: 4730 euro. — Fuel-switching option for heating with establishing an electric vehicle filling station. Additional investment for a 50 kW fast-charging station: 20,000 euro. Investment in an e-vehicle: 35,000 euro.	Fuel-switching options: (1) all produced electricity is used at the household, meeting the total needs of the household for all end-use consumption; (2) selling the excess energy via micro-grid system; (3) for heating, sales of electricity at a privileged renewable electricity price; (4) if heating supply surpasses individual household demand, requires a micro-district heating system or on-farm heating demand; (5) electric vehicle filling station, generating income from electricity sales without grid connection option; and (6) switching to the e-mobility with costless fuel with possible heat use
Produce agro-pellets from APPR for market	Investment in a 500 kg·h^{-1} pellet production line: 25,000 euro. Investment in a tractor attached chipper, with the ability to chip APPR with <127 mm diameter at 6–7 m^3·h^{-1}: 1000 euro. Total investment 26,000 euro.	Sales price of agro-pellets
Selling APPR as chips for the market	Holdings with <5 ha: Investment in a 2500 W wood chipper, with the ability to chip APPR with <45 mm diameter: 250 euro. — Holdings with >5 ha: Investment in a tractor attached chipper, with the ability to chip APPR with <127 mm diameter at 6–7 m^3 h^{-1}: 1000 euro.	Sales price of chips

2.5. Sizing the Annual APPR Demand with the Size of the Perennial Grove

The alternatives for APPR utilization would be related to the quantity available (technical potential) and competitiveness of the (bundle) of produce (economic potential). APPR quantity is directly related to the size of the perennial crop plantation but varies depending on climate zone, crop variety, and landscape. The feasibility of the business models can be assessed with different approaches, depending on the APRR data availability. Table 4 provides aggregated minimum and maximum values

for EU-28 per perennial crop plantations only, including the averages (mean) and the most frequent value (mode). These values provide good indicators to proceed towards various business models, beyond bioenergy. For energy use of APPR, it is better to use values from Table 5. Continuing on Garciá-Galindo et al. [33], results on APPR productivity ratios relative to the surface (t·ha^{-1} d.m.) by crop group by country in EU-28, and lower heating values (LHV) of the selected APPR wood.

Table 4. APPR availability relative to the surface ratio adjusted (t·ha^{-1} d.m.) (source: adaptation of data from reference [33]).

	Min	Max	Mean	Mode
Vineyards	1.05	1.69	1.16	1.05
Olive groves	1.10	1.47	1.12	1.10
Orchards (excl. citrus, nuts)	1.50	2.80	1.89	1.50
Citrus fruits	1.32	4.72	1.83	1.32
Nuts	0.50	1.00	0.70	0.50

Table 5. Lower heating value (LHV) of the selected APPR wood and the average (source: adaptation of data from reference [33]).

LHV (MJ·kg^{-1})	Fruit	Nuts	Citrus	Olive	Vineyard	Average
LHV$_{DM}$ (W = 0%)	17.5	17.2	17.2	16.7	16.8	17.08
LHV$_{DM}$ (W = 20%)	13.5	13.3	13.3	12.9	13.0	13.2

(1) APPR for direct combustion to generate heat for the household: Data for heat demand in our model are based on national data (EIHP, own data). Using the result on final energy consumption in rural households, FEC$_{rh}$ from Equation (2), and dividing it by the number of households, it would give a rough estimation of an average heat demand per rural household.

(2) Direct combustion of APPR to generate both heat and electricity in a CHP plant: For a 50 kW CHP unit with 30% and 40% of electricity and heat efficiency, respectively, and 3000 operational hours only during the heating season, it would need roughly 33 t of APPR per heating season. It is reasonable to expect that both heat and electricity generated in a 50 kW CHP would surpass the demand of a household tenfold. Assuming 12.2 kWh·100 km^{-1} as e-vehicle consumption, a 50 kW CHP unit would be a feasible fuel-switching option for the period when the APPR is available.

(3) Production of agro-pellets for the market would be attractive for an APPR owner if the purchase price of pellets is covering the production costs of agro-pellets and the investment in a pellet production facility.

(4) Selling APPR would be an option that would bring the least value added to the owner but also would allow the least effort. The agreement can be either to collect APPR at the plantation or that the owner delivers the APPR to a collection point. Both options will be reflected in the purchasing price.

The paper ranks the business models according to the perceived attractiveness (SPB, adoption factors, legal framework), based on the triple fit [22].

2.6. Sizing the Replication Rate

National statistics on the structure of perennial groves, as well as geographical distribution, will identify the replication rate for each business model.

The shortest supply chain would be utilizing one's own APPR for direct combustion in individual stoves or boilers for central heating. From the energy point of view, local combustion of APPR for heat (household heating, hot water preparation, on-farm heat for drying, or district heating with micro-grids) would be the most efficient option to utilize primary energy from APPR, minimizing transportation costs and post-harvesting efforts. A rural filling station for e-vehicles is a feasible

option for income diversification and decentralization of energy supply, especially in rural areas with fewer capacity distribution grids. A rural filling station is the most advanced business model and in accordance with the EU vision for a decentralized energy supply [34]. The longer supply chain is to produce agro-pellets for the market. The first option allows household savings while the latter options trigger income diversification and increase.

2.7. Estimating Effects at the Micro Level

To estimate the savings effect, one must compare the prices of fuels for heating as well as the location where the APPR is occurring. Table 2 provides elements for heating price comparisons. Comparison of the percentage of (rural) households with an inability to keep the home warm [35] would give an indication if APPR for household heating could be an energy poverty alleviation or increase the living comfort measure. The average annual distance traveled by car per country or the EU average of 12,000 km [36] would contrast the electric energy demand with the electricity produced in the CHP unit.

2.8. Estimating Effects at the Macro Level

After allocating the most suitable use of APPR in rural households, we use Equations (1) and (2) to calculate the effects on the macro-level in terms of energy savings. In the case of fuel replacement, we estimated the loss of VAT since fuel is not purchased but obtained from its own sources. Also, the gain of VAT in case of stove replacements or vehicle purchasing was estimated. Additional income was estimated with placing APPR as solid biofuel on the market, either as agro-pellets or chips. Based on the estimated additional income with placing APPR as solid biofuel on the market, either as agro-pellets or chips, additional VAT generation was determined. Additional demand for equipment (stoves, pellet lines, wood chippers, filling stations, etc.) should be addressed in the context of the net trade balances.

Fuel replacement affects greenhouse gas (GHG) emissions whose effect can be calculated using the indicators from the European Environmental Agency [37] or national data. If electricity is replaced, the GHG emissions saved would be equivalent to the emissions that occurred during the electricity generation or national electricity generation mix. In 2016, electricity generation's CO_{2eq} emission intensity was 295.8 and 210 g $CO_{2eq} \cdot kWh^{-1}$ for the EU-28 and Croatia, respectively [37].

3. Results and Discussion

The approach was applied to the EU and Croatian average values to demonstrate how the role of APPR in energy planning could be underestimated when applying the classical approach to energy planning. The methodology was also applied to two NUTS-2 regions: Continental Croatia (HR04) and Adriatic (or Mediterranean) Croatia (HR03) to demonstrate the differences when using the average values. Roughly, Continental Croatia has higher annual heating demand than Adriatic Croatia but natural gas is not available in all of Adriatic Croatia.

According to the data of the Croatian Bureau of Statistics, there were 1.5 million ha of the utilized agricultural area in 2018 (1.03 million ha in the Continental region and 0.455 million ha in the Mediterranean region). The area under perennial crops was 71 thousand ha (37.9 thousand ha in Continental and 38 thousand ha in the Mediterranean region). In the structure of perennial crops, orchards participated with about 2.2% while vineyards and olive groves had 1.4% and 1.25% respectively. In case of the absence of national APPR energy potential estimations, there are several EU funded projects, such as Biomass Futures [9], S2Biom [10], and uP_running [27] that give APPR potential both at the EU-28 and member state level. Summer APPR contains a challenging leaf and moisture content to be used for small-scale, mature bioenergy facilities.

Applying the Equations (1) and (3) on the theoretical APPR potential of 227.2 PJ·y^{-1} and 2.01 PJ·y^{-1} for the EU-28 and Croatia, respectively [33], the significance of energy potential of APPR varies but with a specific pattern for each category (Table 6).

Table 6. Linking APPR potential with energy demand in rural households, EU and Croatia (HR).

Area	PE $_{pruning}$ (PJ)	FE $_{pruning}$ (PJ)	FEC$_h$ (PJ)	Share of APPR in FEC$_h$ %	FEC$_{rh}$ (PJ)	Share of APPR in FEC$_{rh}$ %
EU	227.20	181.76	12,066	2%	3379	5%
HR	2.01	1.61	100	2%	46	4%

The share of APPR in final energy consumption of rural households remains low with 5% and 4% for the EU and Croatia, respectively, which is related to the share of rural households in the total number of households which is 28% and 46% for the EU-28 and Croatia, respectively. The possible end-use of APPR potential varies when looking at the EU average values and national values (Croatia) (Table 7). In terms of the end-use of thermal energy, Croatian APPR potential could cover 5% final energy consumption for space heating but one-third for both water heating and cooking. When considering electricity consumption, APPR could cover about a third for electrical appliances and surpass air conditioning energy consumption threefold.

Table 7. Allocating APPR potential as shares (%) in different end-use in households, EU and Croatia.

Area	Space Heating	Water Heating	Cooking	Electrical Appliances	AC
EU	8%	40%	1013%	36%	9%
HR	5%	36%	32%	30%	141%

As a start for evaluation of APPR energy utilization options to the business models, useful heating prices for Croatia (Table 8) were calculated based on the values in Table 2 and current market prices. Table 8 presents gross energy prices for all heating fuels available, by fuel type and energy efficiency of the primary energy conversion.

Table 8. Useful heat energy monetary equivalent to the fuel price by fuel type, Croatia (2019).

Fuel	Gross Energy Price (Eurocent MJ^{-1})	Source
natural gas	1.3728	[38]
woody briquettes	1.4077	National yellow-pages [39]
electricity-black tariff	1.5766	[40]
fuel wood-public forests	1.6467	[41]
fuel wood-private forests	1.7486	National yellow-pages [39]
wood pellets	1.8168	
LPG—propane butane	1.9504	
LPG—butane	2.0221	[42]
light heating oil	2.2526	
wood residues	2.8924	[39]
electricity—red tariff	2.9655	
electricity—blue tariff	3.2658	[40]
electricity—white tariff	3.5661	
diesel fuel	3.090	[42]

The fuel prices in Table 8 indicate the opportunity costs for using APPR in different business models for Croatian APPR owners. The prices of wood (fuelwood from private and public forests) would reflect the savings potential of fuel replacement or supplement. Fuel switching from fossil to renewable solid biofuel would be attractive, especially for electricity, for all fuels but natural gas. Wood chips would reflect the possible market price for APPR.

The business models defined in the methodology are arranged for the EU-28 averages but also placed in the Croatian setting below.

(1)　　The use of APPR for direct combustion to generate heat

For the EU average, 0.92 toe per dwelling and 10.1 koe·m^{-2} of a dwelling of heat are used. Here, we aim at meeting demand with APPR for space heating as the largest share of the average EU-28 end-use thermal demand. As a rule of thumb, a perennial plantation with 2–3 ha (5–6 ha for nuts) would meet the heating demand of an average household in the EU. That is based on 46.22 GJ heating per dwelling, assuming 80% energy efficiency of a wood stove and heating values. The proxies for relating the household heat demand with the perennial crop plantation area (referring to the APPR availability per hectare (Table 4)) are presented in Table 9. The same table contrasts nationally refined data on household heating consumption in Croatia: Continental (HR04) and Mediterranean (HR03) parts.

Table 9. Average size of a perennial crop plantation meet an average EU household space heating consumption (ha).

Perennial Plantation	EU-28 Min	EU-28 Max	EU-28 Mean	EU-28 Mode	HR04 Mean	HR03 Mean	HR Mode
Vineyards	1.56	2.52	2.28	2.52	3.28	1.56	2.70
Olive groves	1.83	2.44	2.40	2.44		1.45	2.51
Orchards (excl. citrus, nuts)	0.96	1.79	1.42	1.79	1.39	0.66	1.15
Citrus fruits	0.59	2.10	1.51	2.10		1.35	2.33
Nuts	2.75	5.50	3.93	5.50	4.00	1.91	3.29

National values to derive an average size of a perennial crop plantation at NUTS-2 level is based on the door-to-door survey of energy efficiency in households and services [43] and national census on population and households in 2011 [44].

(2) Direct combustion of APPR to generate both heat and electricity in a CHP plant

The annual consumption of electricity per dwelling in the EU-28 average and Croatia is similar: 2266 kWh·y^{-1} and 2235 kWh·y^{-1}, respectively [17]. A 50 kW CHP unit would meet the electricity demand of ~20 of both Croatian and EU-28 average) households.

If the electricity produced from the same CHP unit is to be used to charge an e-vehicle, it would suffice to power a car for ~3700 km at the time when the APPR is available. In the case of switching one's own car to a hybrid model, it would cover about 30% of the annual average distance traveled by car of 12,500 km in Croatia [45]. Annual fuel savings would be equivalent to 30% savings for a diesel car, or about 1000 euro per year.

APPR demand, according to the different perennial crop plantations, would assume the sizes as shown in Table 10. For the EU-28 average area of 27 ha, perennial crops (excluding 67 ha for nuts) would be needed to supply a 50 kW CHP unit. For Croatia, the values for fruit orchards and nuts significantly vary from the EU-28 mean and mode values since the pruning yields per hectare of fruit and nuts plantations in Croatia are closer to the EU-28 maximum values.

Table 10. Average size of a perennial crop plantation to meet a 50 kW CHP unit (ha).

Perennial Plantation	EU-28 Min	EU-28 Max	EU-28 Mean	EU-28 Mode	HR Average
Vineyards	18.99	30.56	27.67	30.56	29.44
Olive groves	22.21	29.68	29.15	29.68	27.44
Orchards (excl. citrus, nuts)	11.66	21.77	17.28	21.77	12.51
Citrus fruits	7.12	25.48	18.38	25.48	25.48
Nuts	33.43	66.86	47.76	66.86	35.94

(3) Produce agro-pellets from APPR for market

Agro-pellets are considered of lower quality than the wood pellets which is reflected in the lower market price. If reaching 90% of the wood pellet price of 250 euro·t^{-1} [39], only EU-28 plantations with an average of >92 ha (>222 ha for nuts) could consider such a venture to achieve PB in a year.

Wood pellet prices in Croatia are lower than those of the international market prices (238 euro·t^{-1} in 2019 [46–48] but APPR yields per hectare are closer to the EU-28 maximum values for fruit and nuts plantations, which brings the average size of the perennial crop plantation suitable to consider an agro-pellet production to the similar size to the EU-28 average but starting from 40 ha of orchards.

The minimum agro-pellet production to have a pay-back period of 5 years would be 21–22 t·y^{-1} which is equivalent to the average size of 18.07 and 15.22 ha (44 and 22.58 ha for nuts) for the EU-28 average and Croatia, respectively (Table 11).

Table 11. Average sizes of perennial crop plantations for agro-pellet production, EU-28 averages and Croatian average.

Perennial Plantation	EU-28 Min	EU-28 Max	EU-28 Mean	EU-28 Mode	HR Average
Vineyards	13.02	20.95	18.97	20.95	19.27
Olive groves	14.97	20.00	19.64	20.00	17.65
Orchards (excl. citrus, nuts)	7.86	14.67	11.64	14.67	8.05
Citrus fruits	4.66	16.67	12.02	16.67	15.91
Nuts	22.00	44.00	31.43	44.00	22.58

(4)　Selling APPR chips on the market

This option could be perceived as the least value-added option for the APPR owner and is equal to or less than the wood chips purchasing price at the biomass market that is mostly attached to chipped large, bulk quantities. Solid biomass market for wood chips is still not as mature as the pellet market which generates an opportunity in the local markets that could have high local prices for wood chips. Only in Lithuania, the price span is 139.97–185 euro·t^{-1} [47]. In Croatia, the price of wood chips is about 75–111.26 euro·t^{-1} [39,41,48]. Depending on the investment needed in the alternatives, APPR quantity, wood chips market maturity, and negotiation skills, selling APPR as wood chips might surface as the most lucrative option. There are two business models considered: small holdings (<5 ha) with a production of 1 t·y^{-1} and larger holdings (>5 ha) with minimum production of 10 t·y^{-1}.

From the described business models for APPR, the current investment environment in Croatia supports direct combustion of APPR either as fuel switching or fuel supplement, producing agro-pellets, and selling APPR as chips to the market. The business model that includes micro-grids and involves more than one household in energy consumption remains a challenge for the Croatian countryside. The business models for the energy utilization of APPR are ranked by attractiveness (PB and triple challenge fit) for APPR owners in Croatia in Table 12. Details on PB period calculations for each of the business models are in the Appendix A.

3.1. Sizing the Replication Rate

According to the Farm Register of the Agency for Payment in Agriculture, Fishery and Rural Development, there were 167,676 agricultural holdings in Croatia at the end of 2018 (Table 13). The structure of Croatian perennial crop plantations under analysis is shown in Table 14. The structure of perennial crops and farm size indicate that the shortest business models—fuel supplement or fuel switching and chip production for the market—could be the most suitable options for Croatian rural areas. The latest and the only publicly available data on perennial crop plantations stratification by size, location, and fruit are available from the Agriculture Census in 2003 [49] which is now obsolete. For that reason, the total area of perennial crop plantation by type was reduced by 90% assuming a similar structure of perennial crops with the structure of Croatian agriculture holdings (Table 13). Contrasting area size needed to cover space heating demand in both Continental and Mediterranean parts of Croatia, it would be feasible to have a large replication rate (Table 14): 12,000 and 26,800 perennial crop plantations for Continental and Mediterranean Croatia, respectively, which is 3% and 12%, respectively, of the total households of those two NUTS-02 areas.

Table 12. Ranking of the attractiveness of APPR business models for Croatia.

Rank	Business Model	Investment (Euro)	Savings/Income (Euro·y^{-1})	PB (year)
	Fuel supplement			
1	HR04	No	1288–1367	
	HR03		613–651	
2	APPR as chips-holding >5 ha	1000	750	1.3
3	APPR as chips-holding <5 ha	250	75	3.3
	Fuel switching: Electricity-white tariff			
4	HR04	4730	2231	2.1
	HR03		1062	4.5
	Fuel switching Electricity-blue tariff			
5	HR04	4730	2043	2.3
	HR03		972	4.9
6	Agro-pellet production	25,500	5214	4.9
	Fuel switching Electricity-red tariff			
7	HR04	4730	1855	2.5
	HR03		883	5.4
	Fuel switching light heating oil			
8	HR04	4730	1409	3.9
	HR03		671	7.1
	Fuel switching LPG butane			
9	HR04	4730	1265	3.7
	HR03		602	7.9
	Fuel switching LPG propane butane			
10	HR04	4730	1220	3.9
	HR03		581	8.1
11	A 50 kW CHP unit	>235,500	5959–20,932	>11.3

PB—pay back, HR04—Continental Croatia, and HR03—Adriatic Croatia.

Table 13. The structure of Croatian agriculture holdings [50].

Size of the Farm (ha)	Number of Farms	Share in Total Farm (%)
No land under utilization	11,234	6.7
<4.99	119,385	71.2
5–19.99	27,834	16.6
>20	9222	5.5

Table 14. The structure of Croatian perennial crop plantations (calculations based on references [50,51]) and possible replication rate for fuel supplement or fuel switching for space heating on APPR for Croatia.

Perennial Crop Plantation	Area (ha)	HR04 (No. of Replications)	HR03 (No. of Replications)
Orchards (excl. citrus, nuts)	15,457	7765	6992
Citrus fruit	2260		1673
Nuts	9612	2041	757
Vineyards	23,629	3603	7569
Olive groves	18,656		12,825

Note: assuming locations HR04:HR03 as following: 50:50 vineyards, 85:15 nuts plantations 70:30 fruit production.

3.2. Estimating Effects at the Micro Level

A Croatian household with a >1 ha orchard, vineyard, or olive grove would save 1300 and 630 euro per heating season if supplementing wood with APPR in HR04 and HR03, respectively. That would be about 105 (HR04) to 220 (HR03) euro per month savings from heating fuel expenses. Based on the household structure, about 200,000 (HR04) and 185,000 (HR03) households could benefit from fuel supplement.

In the case of fuel switching, excluding the investment costs, a household would achieve the highest savings when switching from electricity: about 2000 (HR04) and 1000 (HR03) euro per heating season (Table 15) per household. Given the heating fuel structure, fuel switching is more likely to occur on the coast (HR03) with a potential of 15,500 households.

Table 15. Average annual savings of fuel switching with APPR by fuel type per heating season for Continental (HR04) and Adriatic (HR03) Croatia, in euro.

Fuel	HR04	HR03
electricity—blue	2043	972
electricity—white	2231	1062
electricity—red	1855	883
electricity—black	986	469
light heating oil	1409	671
LPG—propane butane	1220	581
LPG—butane	1265	602
pellets	1137	541
natural gas	859	409
briquettes	881	419
fuel wood—public	1030	490
fuel wood—private	1094	521

A fruit producer, olive grower, or vineyard owner could participate in the biofuel market as either APPR pellet or chip producers. Applying the same size structure as for the total Croatian agricultural holdings (Table 12), a potential replication rate would be 1177 candidates for agro-pellets (Table 16). Wood chip production is assumed at a professional level with participation in the market with $>10 \text{ t·y}^{-1}$. The potential replication rate of such perennial crop plantations would be 9457 (Table 16).

Table 16. Potential replication rate for producing agro-pellets and chips from APPR in Croatia.

Perennial Crop Plantation	Agro-Pellets		APPR Chips	
	HR04	HR03	HR04	HR03
Vineyards	196	412	788	1656
Olive groves	0	698	0	2806
Orchards (excl. citrus, nuts)	423	381	1699	1530
Citrus fruits	0	91	0	366
Nuts	111	41	446	166

The minimum additional income from sales is calculated based on the minimum size of both pellet (22 t·y^{-1}) and chip (10 t·y^{-1}) quantity. On the top of the primary production, annual income from sales of APPR as agro-pellets would be about 5200 euro and as APPR chips about 600 euro per holding.

Average disposable income per household was 11,700 euro in 2016, while average equivalized disposable income amounted to 6400 euro [52,53] which indicates an option for APPR use as an energy poverty alleviation measure.

3.3. Estimating Effects at the Macro Level

The effects of utilization of APPR as solid biofuel on VAT generation in Croatia was calculated by multiplying the micro effects and adding 25% of VAT to the turnover (Table 17).

If APPR is to replace electricity heating in rural households, it would reduce $27,050 \text{ t CO}_{2eq}·y^{-1}$ which is 0.2% of the total emissions of CO_{2eq} from the energy sector.

Additional demand for machinery related to domestic production capacities is existing for heating systems. There are national capacities to produce pellet lines and chippers but that production is to be established.

Table 17. Estimated effect on VAT generation when considering APPR as solid biofuel in Croatia.

	Business Model	Replication Rate (In 1000)	VAT (In 1000,000 Euro)		
			Single Time	New Source	Lost Source
1	Fuel replacement				
	HR04	12			3.93
	HR03	27			4.16
2	Fuel switching—electricity	16			4.13
	Heating system adjustments		18.40		
3	Pellet production	2		12.27	
	Pellet line		15.30		
4	Chip production	9		5.62	
	Chipper		2.36		

4. Conclusions

The paper sheds a light on the socio-economic role of APPR use as a solid biofuel. The paper suggests business models that could either alleviate energy poverty in rural areas or increase the competitiveness of perennial fruit and olive growers and vineyard owners. The effects of mobilizing APPR potential via business models are estimated at the micro (households' income) and macro (number of households affected, size of the investment, tax effect, CO_{2eq} savings) levels in Croatia.

The proposed approach to integrate APPR into local energy planning indicated that the traditional approach undermines the APPR energy potential as a sustainable and readily available solid biofuel. From a negligible (0.33%) share in the total EU-28 primary energy demand, APPR energy potential found its place in final energy demand for rural households where it can make 5% and 4% difference at the EU-28 level and Croatia, respectively. With a more precise allocation of APPR supply with the local end-use energy demand in rural households, the value of APPR energy potential is better matched than with the aggregated national end-use energydemand.

Just in the case of two regions in Croatia with different climatic zones: Continental (HR04) and Mediterranean (HR03), the threshold sizes of perennial plots to be included in energy planning vary. A household located on the Adriatic coast would consume 57% of energy (48.53 $GJ·y^{-1}$) of its Continental (85.05 $GJ·y^{-1}$) counterpart. The difference in the final energy consumption pattern is reflected in the thermal end-use (space heating, water heating, and cooking). The difference in energy demand between the regions is linked with the average size of a perennial crop plantation to meet the space heating demand for the Mediterranean and Continental household. With a closer look, APPR from fruit orchards with <1 ha size and located on the Croatian coast are also suitable to meet the space heating consumption of local households.

When considering utilization of APPR for simultaneous production of electricity and heat, even for a micro-CHP unit, larger plots of >7 ha are necessary. A 50 kWh CHP unit would cover electricity demand for about 20 households in both the EU-28 (average) and Croatia. However, the span of EU-28 household electricity consumption is rather wide from 1000 to 5000 depending on the country's level of development and geographical position. In the absence of a legal framework to support the development of micro-grids, an APPR owner could opt for supplying a filling station to power e-vehicles. Generated electricity would support about a third of the annual demand for fuel for an average distance traveled by car in Croatia. Yet, all business models related to CHP demonstrated the least attractive PB period (all beyond 10 years) and were too complex to implement without a clear policy framework. It is our belief that the CHP powered by APPR is the option to be supported with rural development measures as a smart village evolution and micro-grids.

Selling APPR either as agro-pellets or chips indicated economic feasibility without supporting measures in terms of financing, although biomass market maturity would define the attractiveness of these business models.

In Croatia, encouraging utilization of APPR could be considered an energy poverty alleviation measure. Over 10% of household income in 63% of Croatian households is spent on energy which is considered an indicator of energy poverty. A Croatian household with an orchard, vineyard, or olive grove would save 1300 and 630 euro per heating season if supplementing wood with APPR in HR04 and HR03, respectively; they would see 105–220 euro monthly savings from heating and 5%–11% of disposable income saved. In Croatia, 28.5% of households are at risk of poverty or social exclusion, with 24% and 30.8% in Adriatic and Continental Croatia, respectively. In the EU-28 and Croatia, 7.3% and 7.7%, respectively, were unable to keep the home adequately warm. The share of such households was the highest in Bulgaria (33.7%), then Lithuania (27.9%) but highly present within the Mediterranean countries (Greece: 22.7%, Portugal: 19.6%, Italy: 14.1%). With APPR as a supplement to wood heating in individual stoves, some 49 million euro could be available for the Croatian rural community for different spending than for fuel.

Given the structure of space heating in Croatia, APPR could be used as a fuel-saving option in the continental households (aggregated savings of 16 million euro$\cdot$y^{-1}) and as fuel-switching option at the coast (aggregated savings of 16.5 million euro$\cdot$y^{-1} for switching from heating with electricity). Namely, the presence of district heating, a well-developed natural gas grid, and a dominant share of fuelwood for space heating make fuel-switching options not competitive to the existing heating options in the continental area. On the Croatian coast, both fuel supplement and fuel-switching options are attractive as 6% households heat with electricity, peaking with 13%–14% at Dubrovnik-Neretva and Split-Dalmatia counties. At the full potential of APPR for fuel switching and fuel supplementing, a loss of VAT of 12.23 million euro is generated.

On the other hand, if APPR placed on the market as solid biofuels—pellets and chips—VAT will generate 17.7 million euro of one-time investments and 17.9 million euro$\cdot$y^{-1} from annual sales at full APPR potential and current prices.

Although GHG emissions savings are not impressive for Croatia from the fuel switching, this could be a different case for countries with significant fruit production and fossil energy share either in heating or electricity generation mix (e.g. Poland).

The outcomes of this paper give solid indications of which way to direct rural development and clean energy policy in terms of APPR energy potential deployment. The following steps would be developing business models in more detail (operational and maintenance costs) and ranking them not only by financial indicators but also by the perceptions of the rural communities.

Appendix A

Detailed computations of the business models evaluated using the pay-back (PB) period for Croatia:

(1)   Use APPR in direct combustion to generate heat

Fuel supplement option: no investment needed, savings for the household space heating equivalent to wood logs prices (private or/and public wood).

Table A1. APPR as fuel supplement option for Continental (HR04) and Mediterranean (HR03) household (in euro·y^{-1}).

HR04		HR03	
Savings—Public Wood	Savings—Private Wood	Savings—Public Wood	Savings—Private Wood
1288	1367	613	651

Fuel-switching option: investment of 4730 euro needed for heating system adaptations, savings for the household space heating equivalent to the fuels' prices higher than wood logs.

Table A2. APPR as fuel-switching option: savings per year for fuel and pay-back (PB) by fuel type.

Fuel Type	HR04 (Euro·y^{-1})	HR03 (Euro·y^{-1})	PB_HR04 (y)	PB_HR03 (y)
electricity—blue	2043	972	2.3	4.9
electricity—white	2231	1062	2.1	4.5
electricity—red	1855	883	2.5	5.4
electricity—black	986	469	4.8	10.1
light heating oil	1409	671	3.4	7.1
LPG—propane butane	1220	581	3.9	8.1
LPG—butane	1265	602	3.7	7.9
natural gas	859	409	5.5	11.6

(2) Direct combustion of APPR to generate both heat and electricity in a CHP plant

Investment to a 50 kW unit: 4700 euro/kW for CHP plant and 2 × 2500 W home chippers at 250 euro each. Total investment: 235,500 euro. Additional costs for heating system adaptations per household: 4730 euro.

Table A3. APPR to cover electricity consumption of households with fuel switching in Croatia.

Electricity Savings (Euro·y^{-1})		Heat Savings		Total (Euro·y^{-1})	PB (y)
		Fuel Type	(Euro·y^{-1})		
Average savings	4606				
		electricity—blue	7054	11,660	28.31
		electricity—white	7703	12,309	26.82
		electricity—red	6405	11,012	29.98
		electricity—black	3405	8012	41.20
		light heating oil	11,906	16,512	19.99
		LPG—propane butane	12,905	17,511	18.85
		LPG—butane	11,595	16,201	20.37
		natural gas	7709	12,316	26.80

Fuel-switching option: all produced electricity is used at the households meeting total needs of household for all end-use consumption. Both heat and electricity production surpass individual household demand which requires a micro-grid system.

Table A4. APPR to cover all end-use needs of a household in Croatia.

Tariff Model	Electricity Savings (Euro·y^{-1})	Heat Savings (Euro·y^{-1})	Savings Total (Euro·y^{-1})	PB (·y)
electricity—blue	5290	7054	12,345	19.1
electricity—white	5777	7703	13,480	17.5
electricity—red	4804	6405	11,209	21.0
electricity—black	2554	3405	5959	39.5

Fuel-switching option for heating with sales of electricity at a privileged renewable electricity price. Heating supply surpasses individual household demand which requires a micro-district heating system or on-farm heating demand. Privileged price set at 17.84 eurocents kWh[-1]. Investment in central heating system not needed.

Table A5. APPR to cover heating of a household in Croatia with sales of electricity to the grid at privileged price and fuel-switching savings.

Fuel Switched	Electricity Sales (Euro·y^{-1})	Heat Savings (Euro·y^{-1})	Sales + Savings Total (Euro·y^{-1})	PB (y)
	8027			
light heating oil		11,906	19,933	11.8
LPG—propane butane		12,905	20,932	11.3
LPG—butane		11,595	19,622	12.0
natural gas		7709	15,736	15.0

Fuel-switching option for heating with establishing an electric vehicle filling station. Additional investment for a 50 kW fast charging station: 20,000 euro. Price of base electricity at the CROPEX exchange rate: 36.13 euro·MWh^{-1}.

Table A6. APPR to cover heating of a household in Croatia with sales of electricity at charging station and fuel-switching savings.

Fuel Switched	Electricity Charging (Euro·y^{-1})	Heat Savings (Euro·y^{-1})	Sales+Savings Total (Euro·y^{-1})	PB (y)
	1626			
light heating oil		11,906	13,532	18.9
LPG—propane butane		12,905	14,531	17.6
LPG—butane		11,595	13,220	19.3
natural gas		7709	9335	27.4

(3)   Produce agro-pellets from APPR for market

Investment in a 500 kg h^{-1} pellet production line: 25,000 euro. Investment in a tractor attached chipper, with the ability to chip APPR with <127 mm diameter at 6–7 m^3·h^{-1}: 1000 euro. Total investment: 26,000 euro. To achieve a 5-year PB to pay off the investment in the pellet line at 105 euro·t^{-1}, 22 t of agro-pellets from pruning must be produced.

(4)   Selling APPR as chips

Holdings with <5 ha: Investment in a 2500 W wood chipper, with the ability to chip APPR with <45 mm diameter: 250 euro. PB at 3.33 years.

Holdings with >5 ha: Investment in a tractor attached chipper, with the ability to chip APPR with <127 mm diameter at 6–7 m^3·h^{-1}: 1000 euro. PB at 1.33 year.

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